Geological Survey Research 1962

Synopsis of Geologic, Hydrologic, and Topographic Results

GEOLOGICAL SURVEY PROFESSIONAL PAPER 450-A

Geological Survey Research 1962

THOMAS B. NOLAN, *Director*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 450

A synopsis of results of geologic, hydrologic, and topographic investigations for fiscal year 1962, accompanied by short papers in the fields of geology, hydrology, topography, and allied sciences. Published separately as Chapters A, B, C, D, and E

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

FOREWORD

The reception accorded the 1960 and 1961 Annual Reviews of Geological Survey research has encouraged us to prepare this volume, "Geological Survey Research, 1962," in a continuing effort to publish more quickly the significant results of our current investigations. We continue to consider these reports as experimental and have again this year modified the content, format, and frequency of release of chapters in an attempt to serve better the interests of the users of the reports. The comments and suggestions of these users are here solicited and will be considered carefully as future volumes are planned.

The current Annual Review consists of five chapters (Chapters A through E) of Professional Paper 450. As in the preceding two Annual Reviews, Chapter A is a synopsis of recent findings in the many and varied lines of study pursued by Survey personnel. Chapters, B, C, D, and E of this volume are collections of short articles in geology, hydrology, topography, and allied fields. These articles are numbered as follows:

Prof. Paper 450–B	Articles 1–59
Prof. Paper 450–C	Articles 60–119
Prof. Paper 450–D	Articles 120–179
Prof. Paper 450–E	Articles 180–239

These four chapters have been released at about three-month intervals during the year (Chapter E is in preparation as this foreword is written) so that timely articles could reach the reader more quickly.

Results of research presented in this chapter, Chapter A, are representative of our many projects; complete coverage of all projects would result in an unwieldy volume. A complete list of our publications during fiscal year 1962 can be found on pages A197 to A250 Readers interested in learning of our current work in certain geographic areas or on specific topics will find a complete listing of investigations in progress in the Geologic and Water Resources Divisions during fiscal year 1962 on pages A137 to A186. The status of mapping by the Topographic Division is included this year for the first time, on pages A187 to A195, Addresses of our main centers and field offices and names of officials in charge are presented on pages A128 to A132 for readers who wish to contact our personnel directly.

During fiscal year 1962, the services of the Geological Survey were utilized by or were supported financially in part by, the numerous Federal, State, County and City agencies listed on pages A133 to A136. Some work reported in these chapters may be a direct result of cooperative investigations in previous years with agencies not shown on the current list. Cooperating agencies are acknowledged in the articles in Chapters B, C, D, and E, but space limitations preclude mention of individual cooperators in the summary statements in Chapter A.

The current Annual Review represents the combined efforts of many individuals. Arthur B. Campbell assumed overall responsibility for the preparation of the report and assembled Chapter A from information supplied by many project chiefs and program leaders. He was assisted by Joshua I. Tracey, Jr., who critically reviewed the manuscripts for Chapters B, C, D, and E. Marston Chase was responsible for all technical editing, preparation of indexes, and for the myriad tasks required to convert author's manuscript to printed article. Edith Becker assisted in these duties at times during final preparation of manuscripts for the Government Printing Office and in the handling of proof copy. William H. Elliott was responsible for planning and preparing illustrations for all chapters. Michael S. Chappars served as an advisor during the preparation of the volume. Robert A. Weeks, James R. Randolph, and John B. Rowland assembled lists of cooperating agencies, the list of investigations in progress, and status of topographic surveys and maps. Margaret Cooper and her staff compiled the list of publications. Nancy Pearre prepared the instructions for ordering Geological Survey publications. Robert B. Raup, Jr., and George H. Davis, who acted as technical reviewers of Chapter A, were helpful in the selection, organization, and expression of the material presented in that chapter. I am pleased to acknowledge the contributions of the many persons who presented the result of their scientific work in this volume.

THOMAS B. NOLAN, *Director*.

Synopsis of Geologic Hydrologic, and Topographic Results

Prepared by members of the Geologic, Topographic, and Water Resources Divisions

GEOLOGICAL SURVEY RESEARCH 1962

GEOLOGICAL SURVEY PROFESSIONAL PAPER 450-A

A summary of recent scientific and economic results, accompanied by a list of publications released in fiscal 1962, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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RESOURCE INVESTIGATIONS

In response to the ever-changing but ever-growing demands for minerals and mineral fuels, the Geological Survey is placing more emphasis on the compilation and analysis of resource information and is accelerating research on problems bearing on their discovery, appraisal, and effective development. Water is likewise a critical resource, and the Survey is expanding its programs of basic research to improve capabilities for analyzing and solving water-supply problems.

To achieve coordination of the varied mineral-resource studies underway or planned, and to provide timely and comprehensive information on mineral supplies for both government and industry use, the Geological Survey formed a Resources Research Group in April 1962. A major aim of this group is to stimulate the preparation and publication of authoritative reports on mineral commodities but, in addition, it will undertake studies of a wide variety of topical problems relating to the origin of mineral deposits and the means to find them.

Another important development in the resource field is the instigation of a program to accelerate collation and synthesis of data on the distribution of elements in the earth's crust (particularly those of economic significance and those bearing on the incidence of disease) and on the processes by which they are concentrated.

In the field of water resources, the Survey is making a special effort to stimulate hydrologic education because of the inadequate number of men sufficiently trained in hydrology and the water sciences. Steps being taken include working with universities toward the improvement of college curricula and sponsoring advanced training activities.

New findings in the fields of heavy metals, light metals and industrial minerals, radioactive materials, fuels, and water are summarized in the following pages.

HEAVY METALS

DISTRICT AND REGIONAL STUDIES

Iron deposits in the Birmingham district, Alabama

R. P. Sheldon has found that the deposition and character of the hematite ores of the Birmingham district were closely controlled by physical sedimentation during Silurian time when they were deposited. Sedimentary structures, lithology, and stratigraphy indicate that the ores are related to barrier islands built by southwestward longshore drift of sand from the northeast. The self-fluxing calcareous ores were deposited on the lagoon side; this calcite-hematite facies grades southeastward in part into a siderite-chamosite reduced facies and in part into a dark claystone facies. Seaward (to the northeast) the hematite facies grades into hematite-quartz sandstone, which makes up most of the barrier islands, and this in turn grades into marine nonferruginous sandstone.

Iron ore in Michigan

In a comprehensive report on the geology of central Dickinson County, Mich., H. L. James and others (1961) estimate that the principal iron-formation, the Vulcan, contains 450 million tons of material averaging about 35 percent iron. The authors emphasize that much of this is at best potential ore, but note that high-grade pelletized concentrates are being produced from this material at one mine in the area.

Iron deposits in Montana

According to H. L. James and K. L. Wier, the Ramshorn iron deposit in the Tobacco Root Range, Madison County, Mont., is another metamorphosed sedimentary iron-formation like the Carter Creek and Kelly deposits reported last year (U.S. Geological Survey, 1961 w, p. A1). The iron-formation here, which is about 50 feet thick, occurs in a sequence of Precambrian dolomite, quartz-mica-garnet schist, quartzite, and amphibolite. The deposit has the form of an overturned syncline, open to the north, whose west limb is cut off by intrusive rock.

Iron deposits in Nevada

Iron ore occurs in a volcanic sequence of Jurassic(?) age in the northern Cortez Mountains, Eureka County, Nev., according to L. J. P. Muffler, who has divided the sequence into a graywacke unit (lower), an ash-flow tuff unit, and a flow unit (upper). Hydrothermal alteration and mineralization have affected all the units, but the potentially commercial deposits are restricted to the upper unit.

Iron-copper deposits in southeastern Alaska

L. A. Warner and E. N. Goddard (1961) estimate that the iron and copper-bearing deposits of Kasaan Peninsula, Prince of Wales Island, southeastern Alaska, have reserves of about 4 million long tons of ore averaging 50 percent iron and 1.5 million short tons of copper ore, most of which contains less than 2 percent copper. Magnetite, pyrite, and chalcopyrite in a garnet-epidote-diopside-hornblende gangue replaced brecciated greenstone and interbedded clastic sedimentary rocks. The broader regional setting of these deposits and of occurrences of gold, silver-lead-zinc, molybdenum, and palladium are described by Condon (1961) in a report on the geology of the Craig quadrangle.

Tin in Alaska

Sulfide-bearing greisen on the north side of a body of granite 1 mile southeast of the Lost River mine in the York Mountains was re-examined by C. L. Sainsbury, who found it to be identical to greisen at the Lost River mine that contains economic deposits of cassiterite. The greisen is intersected by an altered dike that is also sulfide bearing. Geologic similaries between this recently examined area and the Lost River mine give new economic importance to the area.

Chromite deposits in the Stillwater Complex, Montana

E. D. Jackson (1962) has correlated the five major chromite-bearing zones of the Stillwater Complex, south-central Montana, and has shown that they can be traced along strike at least 15 miles. Total iron in the chromite from the footwalls of these zones is almost constant along the strike of any one zone but decreases regularly upward from the lower zones toward the middle ones and then increases again. On the other hand, the ratio of ferric iron to total iron in the chromite is almost constant from zone to zone but decreases laterally from each end of the complex toward the center. The regularity of these variations, together with the within-zone changes reported by Jackson, Dinnin, and Bastron (U.S. Geological Survey, 1961w, p. A1), should aid in locating commercial-grade chromite.

Mineral deposits near Philipsburg, Montana

W. C. Prinz has recognized several stages of mineralization in the Philipsburg district, Montana. The most important are, from oldest to youngest: zinc, lead, silver-copper, and manganese. Variation in composition, character, and distribution of the ore bodies and the crude zoning within the district are explained by progressive changes both in time and space in structural conditions and composition of the ore solutions. The mineral composition of an individual deposit was governed by the stages of mineralization during which its controlling structures were open to receive ore solutions, and the type of deposit (steeply dipping vein, bedding vein, or irregular replacement) by the structural conditions that existed when the solutions were introduced.

Copper-zinc deposits in northern California

J. P. Albers and J. F. Robertson (1961) believe, as did earlier geologists, that the copper-zinc-bearing massive-sulfide deposits of the East Shasta district, California, were formed by replacement of intrusive igneous, volcanic, and sedimentary rocks. They suggest, however, the following alternatives to the traditional magmatic source for the mineralizing solutions. The greenstones and andesites of the eugeosynclinal assemblage in which the deposits occur contain metals in ample quantities to account for the sulfide deposits and undoubtedly trapped large amounts of sea water that could have been heated and mobilized by deep burial, radioactivity, or proximity to a magma. Granitization of the mafic rocks, for which there is some evidence, would also release metals from ferromagnesian minerals and make them available for concentration into ore bodies.

Copper deposits in sandstone in the Southwestern States

C. B. Read divides the numerous copper deposits in sandstone of the Southwestern States into two groups on the basis of their structural character and the presence or absence of associated organic material. Deposits of one group are in fractures or permeable zones, organic material is absent or rare, and evidence for hydrothermal activity suggests primary mineralization by telethermal solutions. Deposits of the other group occur in sandstone or shale with carbonaceous or, in places, bituminous material and syngenetic iron sulfide or carbonate laid down under reducing conditions. Subsequent introduction of the copper and replacement of part of the iron may have been by hydrothermal solutions but most commonly seem to have been by meteoric water.

Lead, zinc, and related ores in the Central and Eastern States

A. V. Heyl, Jr., and M. R. Brock (Art. 148)[1] have found the first known zinc deposit in Ohio at Serpent Mound. Coarse-grained yellow and orange sphalerite occurs in Silurian limestone in a 2-acre area of shatter breccia near the center of this well-known explosion structure. A complex history of brecciation, cementation, faulting and introduction of cherty jasperoid, renewed brecciation and deposition of sphalerite, and final fracturing of the sphalerite indicates that Serpent

[1] Article 148 in Professional Paper 450–D. All references to articles in Chapters B, C, and D are given in this style. Articles 1–59 are in Chapter B, articles 60–119 are in Chapter C, and articles 120–179 are in Chapter D.

Mound developed in successive stages rather than during a single explosive event.

Epithermal fluorite and lead-zinc veins in the central Kentucky district seem to be related to fractures developed on the collapsed Lexington Dome, according to Janice Jolly and A. V. Heyl, Jr. Fluorite is more abundant in the center and lead-zinc minerals at the periphery of the district; this zonal pattern is similar to that of the Cumberland district, England.

The zinc deposits at Friedensville, Pa., have been examined by A. V. Heyl, Jr., M. R. Brock, D. M. Pinckney, and E. W. Roedder, who report that the ore is in replacement veins along northeast-trending faults and in bedding planes, in crackle breccia as open-space filling, and in a major mylonite zone that dips under the ore body at a low angle. Microcline in quartz veins, fluid-inclusion measurements, and the presence of minor amounts of copper suggest a fairly high-temperature origin.

Massive-sulfide copper deposit in North Carolina

A. R. Kinkel finds that at the Ore Knob copper mine, Ashe County, N.C., ore textures give little clue to original mineral relations because the sulfides and adjoining gneiss have been recrystallized. Unoriented micas and other silicates, mutual growth of sulfides and silicates, coarsening of grain size, and probable change from pyrite to pyrrhotite followed by late growth of pyrite porphyroblasts suggest recrystallization under rising temperature.

Magnetite deposits in New York

Further chemical studies by B. F. Leonard and A. C. Vlidsidis (1961) on the minerals of the Jayville magnetite deposit, St. Lawrence County, N.Y., have shown that a borate mineral, presumably vonsenite, is a major constituent of part of the ore. Core from one drill hole contained 4.80 percent B_2O_3, equivalent to about 36 weight percent vonsenite if all the boron is present in that mineral.

Studies in Utah

In a comprehensive description of the stratigraphy of the East Tintic Mountains, which provides the background for a detailed report on the structure and deep ore zones of the Tintic mining district that is in preparation, H. T. Morris and T. S. Lovering (1961, p. 99–104) give data on the vanadiferous phosphatic shale member of the Deseret Limestone. Parts of this member approach, in composition and thickness, some phosphorites utilized commercially in the thermal-reduction method of producing elemental phosphorus. In other areas vanadium is already being recovered from the slags produced from similar phosphorites of the Phosphoria Formation.

H. T. Morris (Art. 60), together with J. A. Anderson of the Bear Creek Mining Co., worked out the prevolcanic topography of the Tintic-East Tintic district from surface and subsurface data. The volcanic rocks were laid down on an old erosion surface having relief of more than 4,400 feet. This information will help the search for additional concealed ore bodies by showing in which areas the blanket of barren lavas is relatively thin.

M. D. Crittenden, Jr., and others (1961) note that intense hydrothermal-alteration effects, sanded dolomite, and jasperoid bodies in the Drum Mountains, west-central Utah, closely resemble alteration effects associated with ore in the Tintic district. They suggest that abundant near-surface manganese carbonate and sulfide mineralization may give way to proportionally larger amounts of base metals in depth.

Geologic mapping by M. D. Crittenden, Jr., east of Park City shows that the youngest intrusive rocks near Keetley intrude the base of the adjoining volcanic rocks. Recognition that the contact is intrusive rather than sedimentary increases the economic interest in areas of marked alteration.

Silver in silicified rocks, Nevada and Washington

Silver-bearing deposits in the Taylor mining district, 15 miles southeast of Ely, Nev., are restricted to silicified Paleozoic limestone, particularly to thin-bedded or shaly limestone beneath thick shale formations, according to Harald Drewes (Art. 1). The silicification and introduction of sulfide ore minerals appear to have been related to faulting. The mineralization may also be related to porphyritic rhyolitic dikes trending in the same general north to northeast direction as the faults and silicified zones.

In the Bodie Mountain quadrangle, northeastern Washington, R. C. Pearson has mapped an extensive silicified zone at the contact of Tertiary volcanic rocks with older metamorphic rocks. The zone, explored only by shallow prospect pits, contains minor amounts of silver and is paralleled by narrow quartz veins, including the silver-bearing Zala M. vein.

Copper ore in Idaho

At the Empire mine, near Mackay, Idaho, replacement bodies of primary and secondary copper ores occur within or near tactite, along an arcuate contact between granitic rocks of early Tertiary age and limestones of Carboniferous age. In the lower levels of this mine, T. H. Kiilsgaard has found that steeply plunging, irregular, pipelike bodies of primary ore form where northeast-trending premineralization faults cut the tactite, and he reasons that the jointed and fractured tactite was more permeable to mineralizing solutions ascending along the faults than were the limestones and granitic rocks. Kiilsgaard's conclusions support, in part, the earlier conclusions of Umpleby.[2]

Copper and molybdenum mineralization in San Juan, Puerto Rico

A belt of mineralized quartz diorite porphyry adjacent to a large west-northwest-trending fault has been found by M. H. Pease, Jr., near La Muda, about 8 miles due south of the center of San Juan. The ore minerals occur as sulfides, chiefly chalcopyrite, but with significant amounts of molybdenite as well. Pyrite is found both in the intrusive rocks and in the adjacent volcanic rocks, but the copper and molybdenum sulfides appear to be concentrated in veinlets trending at an angle to the principal fault. Companies that hold exploration permits granted by the Puerto Rico Mining Commission are using geochemical and physical methods to prospect the La Muda area as well as the earlier known Lares and Utuado mineralized areas.

TOPICAL STUDIES

Manganese

D. F. Hewett has continued his studies of the manganese oxides reported earlier by Hewett and Fleischer.[3] Semiquantitative spectrographic analyses of the heavy-metal content of 32 vein oxides thought to be of hypogene origin strengthen his conclusion that the veins of manganese oxides in early and middle Tertiary volcanic rocks in New Mexico, Arizona, Nevada, and southern California may be succeeded in depth by veins with abundant rhodochrosite and rhodonite and sulfides of lead, zinc, copper, and silver. The analyses show noteworthy contents of tungsten, lead, copper, arsenic, antimony, thallium, barium, and strontium, whereas the sulfide-bearing manganese carbonate and silicate veins contain huebnerite, base-metal sulfides, sulfarsenides, sulfantimonides, and barite.

Jasperoid

T. G. Lovering and J. C. Hamilton (Art. 63) have made a statistical study of the physical, mineralogical, and chemical characteristics of jasperoid samples from various districts in western conterminous United States to learn whether they can be useful in the search for sulfide ore deposits. They find that 19 characteristics are significantly more abundant in ore-related samples and 8 in non-ore-related samples. The most significant physical and mineralogical characteristics of ore-related jasperoid are: phaneritic texture, abundant vugs, wide range in size of quartz grains, presence of abundant elongated quartz grains, and presence in oxidized samples of orange goethite and jarosite. Semiquantitative spectrographic analyses of these samples show that concentrations of the following elements are highly significant of ore-related jasperoid: Ag>0.00015 percent; Pb>0.0015 percent; Zn>0.015 percent, Cu>0.003 percent; Mo>0.0007 percent, and Bi>0.0007 percent. The recognition and evaluation of these characteristics should aid the exploration geologist in identifying jasperoid bodies that may have a close proximity to blind ore deposits.

Thermoluminescence

C. H. Roach, G. R. Johnson, and J. G. McGrath report that the white and dark-gray dolomite phases of the principal host rock at the Eagle mine, Gilman, Colo., have significantly different thermoluminescent characteristics. Glow curves of the dark-gray dolomite consistently have two peaks, whereas those of the white dolomite have only one. Although the intensity of thermoluminescence of the dark-gray dolomite does not vary systematically with distance from ore, that of the white dolomite does, being low near ore and increasingly higher away from it. Systematic variation in one thin marker bed extends outward 8,000 feet from ore and indicates that thermoluminescence might be useful in exploration at Gilman.

Fluid inclusions

Minute cavities in ore and gangue minerals contain fluids believed to be samples of the original mineralizing solutions. Techniques for determining the chemical and isotopic nature of these solutions and their temperatures at the time of ore deposition have been applied to minerals from various districts. W. E. Hall and I. R. Friedman report that ores in the Illinois-Kentucky fluorspar-zinc district and the Wisconsin zinc-lead district were deposited from concentrated brines rich in sodium, calcium, and chlorine. The deuterium content of the solutions decreases in the later minerals. E. W. Roedder and D. M. Pinckney find that the temperature of formation in the Mississippi Valley-type ores ranged from 185° C to 207° C in east Tennessee, 120° C to 160° C in southern Illinois, was about 120° C in the Tri-State district, Oklahoma-Kansas-Missouri, and ranged from 80° to 100° C in Wisconsin.

Fluid-inclusion and mineralogical studies by D. M. Pinckney of numerous veins in the northern part of the Boulder batholith, Montana, have shown that the veins belong to a gradational series arranged in a broad zonal pattern, rather than to two distinct types of different ages as was previously thought. The temperature of formation ranged from 300° C for the central type, which consists largely of quartz and sulfides, to about 200° C for the peripheral type, made up chiefly of chalcedony and rhombic carbonates.

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[2] Umpleby, J. B., 1917, Geology and ore deposits of the Mackay region, Idaho: U.S. Geol. Survey Prof. Paper 97, p. 44–49.

[3] Hewett, D. F., and Fleischer, Michael, 1960, Deposits of the manganese oxides: Econ. Geology, v. 55, no. 1, p. 1–55.

E. W. Roedder reports the unexpected discovery of liquid CO_2 in primary fluid inclusions in quartz crystals from the Red Devil mercury-antimony mine, southwestern Alaska. The wide range of CO_2–H_2O ratios in different inclusions, plus the uniform homogenization temperatures for the CO_2 liquid and gas phases, implies the existence, at the time of ore deposition, of two immiscible fluids—globules of a dense supercritical CO_2 phase in a water phase—at pressures nearly equal to the rock pressure.

Aeromagnetic prospecting for iron ore

G. D. Bath has found that in the Mesabi area of northern Minnesota the aeromagnetic anomalies that occur over bedded iron-formations of Precambrian age can be satisfactorily explained only after considering the effects of both induced and remanent magnetization. The induced magnetization, which is related to the magnetite content of the rock, will not explain all of the anomalies, and it must be concluded, therefore, that a magnetic anomaly may not give a reliable indication of magnetite content. At the present time the utility of the magnetic method of prospecting, and in particular its ability to indicate magnetite content, is of fundamental importance to the mining industry. The purpose of a recently completed report[4] is to present the magnetization data that are required to explain the anomalies from the Biwabik Iron-Formation of the Mesabi area and to suggest that this evaluation of the induced and remanent magnetization of an iron-formation of known magnetite content may help to explain the magnetic anomalies over similar iron-formations elsewhere in the world. This valuation can be used as a basis for explaining aeromagnetic anomalies from correlatives of the Biwabik Iron-Formation in the Gunflint, Cuyuna, and Gogebic districts of the Lake Superior region.

COMMODITY STUDIES

R. P. Fischer (1961) has analyzed statistical data on the production, shipment, and consumption of vanadium, which show a changing and puzzling picture. Until 1955, United States exports were small, but in recent years certain European countries and Japan have been taking quantities greatly in excess of the amounts that traditional uses for alloying with steel would require. Some new use or uses may have been developed, but none is known that seems to account for the upsurge in demand, and the future of the vanadium industry is uncertain.

E. T. McKnight has assembled data on the history of silver production in the United States and on resources to meet future needs. The greater part of our output now is derived as a byproduct or coproduct of base-metal mining and therefore is dependent on the prices and demand for lead and copper. He foresees that annual domestic capacity should remain above 30,000,000 ounces for a number of years.

LIGHT METALS AND INDUSTRIAL MINERALS

DISTRICT STUDIES

Beryllium deposits in the Tarryall area, Colorado

Geologic mapping by C. C. Hawley in the Tarryall quadrangle, Colorado, shows that the Pikes Peak Granite occurs as a large lobe-like body extending southward from the main Pikes Peak batholith, as numerous dikes, and as a small stock cutting older Precambrian rocks. The Boomer mine beryllium deposit is associated with this stock. Mapping in the large lobe-like body has shown that three main types of granite can be distinguished on the basis of texture, grain size, and type of inclusion: medium-to-coarse-grained granular rocks form the outer part of the lobe, and concentrically within are fine- or medium-grained seriate porphyritic granite and aplite. All of the known beryllium deposits in this lobe are in greisens associated with the latter two rock types.

Beryllium deposits at Spor Mountain, Utah

Beryllium deposits in the Thomas Range, Utah, are on the west and east sides of Spor Mountain. All the beryllium deposits contain fluorite, but the high-grade fluorite deposits on the central part of Spor Mountain contain only trace amounts of beryllium. Most of the beryllium deposits are in tuff, although a little beryllium has been found by M. H. Staatz and W. R. Griffitts (1961) in dolomite adjacent to the tuff. Studies by Staatz suggest that the beryllium deposits are related to the magma that formed fluorine-rich rhyolite in the region. The field relations suggest that the Spor mountain deposit may be another in which beryllium was transported by a soluble complex fluorine ion that was stabilized by excess fluorine in the solution. The high-grade fluorite deposits would thus represent precipitation of this excess fluorine in the central part of the area permeated by hydrothermal solutions, and the peripheral beryllium deposits would represent precipitation from these outward-moving solutions after the excess fluorine was lost.

Beryllium minerals in the York Mountains, Alaska

Geologic mapping by C. L. Sainsbury in the York Mountains, Alaska, has disclosed an extensive area, hitherto unknown, containing beryllium minerals in fluoritized limestones similar to those associated with the Lost River mine 5 miles to the east (Sainsbury and others, 1961).

[4] Bath, G. D., 1962, Magnetic anomalies and magnetizations in the Biwabik Iron Formation, Mesabi area, Minnesota: Geophysics. (In press.)

Pegmatites in the Blue Ridge area, North Carolina

F. G. Lesure has found that the pegmatites of the Franklin-Sylva district contain cataclastic structures similar to the structures in the Spruce Pine pegmatites that he reported previously.[5] Preliminary study of data on 1,500 mica mines in all the districts of the Blue Ridge of North Carolina and Georgia indicates that the Blue Ridge pegmatites in general are more severely deformed than similar pegmatites in the southeastern Piedmont.

Aluminum deposits in Hawaii

Investigations by S. H. Patterson of alumina-rich soil and weathered rock in deeply weathered basalt lava flows of Kauai, Hawaii, show that the thoroughly weathered rock at the surface is rich in gibbsite (trihydrate of alumina) and secondary iron minerals, and that very fine grained titanium minerals are common. The clay-mineral halloysite is a minor component of the rock at the surface but increases in abundance with depth, and in general the downward increase in halloysite is accompanied by a decrease in gibbsite. Resources of low-grade ferruginous bauxite in surficial deposits are estimated at 110 million tons. The principal chemical components of this resource, in percent, are approximately 4.7 SiO_2, 25.9 Al_2O_3, 39.4 Fe_2O_3, 6.7 TiO_2, and 20.0 combined water. Also present are very large tonnages of weathered rock having similar percentages of alumina but undesirably higher percentages of silica.

Phosphate deposits in Arkansas

Investigation by J. B. Cathcart of the Peyton Creek phosphate deposit in Arkansas has shown that the deposit is apparently a channel filling of Mississippian age. Although the exposed phosphorite rauges from 1 to 23 feet in thickness, the top of the bed is almost a plane. The extent of the deposit is not known. This one deposit is probably not large enough to be economic, but there may be other similar deposits in the area at this stratigraphic horizon, and together they might constitute a workable resource.

Phosphate deposits in Florida

The phosphate deposits of the land-pebble district of Florida are mostly in the lower unit of the Bone Valley Formation of Pliocene age. Studies by J. B. Cathcart have shown that the eastern extent of these deposits was limited by a low ridge in the Hawthorn Formation of Miocene age. The sea in which the Bone Valley Formation was deposited was temporarily restricted by this ridge, and the phosphorite of the formation thins markedly on its western flank. The upper unit of the Bone Valley Formation extends across the ridge.

Although the lower unit of the Bone Valley Formation grades into the upper unit in most of the phosphate district, small outliers of the lower unit in the northernmost part of the district indicate an erosional unconformity between the two units. The sea in which the lower unit of the Bone Valley was deposited probably withdrew slightly and then readvanced beyond its previous shoreline, so that the upper unit of the formation overlapped both the lower unit and the ridge in the Hawthorn Formation, and extended to the area underlain by the Tampa Limestone of Miocene age north of the land-pebble district.

Phosphate nodules in Montana

A zone of phosphatic nodules in the basal 30 feet of the Colorado Shale exposed in the Bearpaw Mountains, Mont., is reported by W. T. Pecora, B. C. Hearn, Jr., and Charles Milton (Art. 12). The nodules, which can be easily removed from the unweathered shale, constitute less than 2 percent of the shale but contain an estimated 33 percent P_2O_5.

Potash deposits in the Carlsbad district, New Mexico

Data compiled by C. L. Jones and B. M. Madsen from the Carlsbad potash district, New Mexico, continue to furnish evidence of large-scale replacement of evaporites by potassium-bearing minerals. This concept supersedes those held when the district was discovered, and provides an improved basis for exploration within the district and possibly elsewhere. The replacement occurred in two distinct stages: (1) a diagenetic stage characterized by development of dolomite or magnesite at the expense of calcite, and anhydrite at the expense of gypsum, and (2) a metasomatic stage involving an influx of potassium- and magnesium-bearing brines resulting in the development of polyhalite at the expense of anhydrite, and sylvite and associated bittern salts at the expense of primary halite.

Saline minerals in the Searles Lake area, California

Mapping and X-ray studies by G. I. Smith show that evaporite minerals are common in the upper Quaternary lake sediments exposed around the edge of Searles Valley, Calif. Valuable deposits of contemporaneous salines lie beneath the surface of Searles Lake, in the center of this valley. The evaporite minerals most commonly found in the exposed sediments are fine-grained aragonite, calcite, halite, and dolomite, and efflorescent thenardite and ulexite. Many of the lower Wisconsin(?) sediments contain calcite and only subordinate aragonite, whereas the upper Wisconsin(?) and Recent sediments contain aragonite and subordinate calcite. This probably reflects an increasing salinity in the younger lakes. The mineralogy, lithology, and dis-

[5] Lesure, F. G., 1959, Deformation in pegmatites of the Spruce Pine district, North Carolina [abs.]: Geol. Soc. American Bull., v. 70, no. 12, pt. 2, p. 1766.

tribution of some of the exposed sediments also indicate that the large lakes in which they formed were stratified, with the dense brines created during the previous low stand of the lake constituting the lower layer. These indications of increasing salinity and stratification reflect the large quantities of soluble salts that accumulated in the basin during late Quaternary time, and criteria indicating this history in other areas may be useful in appraising the likelihood of concealed salines in those basin centers.

Clay in Kentucky

A subsurface-contour map has been made of the Olive Hill Clay Bed of Crider[6] of northeastern Kentucky in a cooperative study with the Kentucky Geological Survey. According to J. W. Hosterman, the clay bed was deposited throughout the area except where the underlying Upper Mississippian limestone units formed positive areas during the time of clay accumulation, or where clay minerals were not formed by leaching and recrystallization because there was no swamp environment. Parts of this clay bed are also missing where removed along channels eroded prior to deposition of the sandstone facies of the Lee Formation of Pennsylvanian age.

Clay in Washington and Idaho

Geologic studies by J. W. Hosterman have delineated several areas of clay in a belt across the southern part of the Greenacres quadrangle, Washington and Idaho. Four types of clay can be distinguished on the basis of their parent material or extent of transport. Three are residual clays formed during the Tertiary by intense weathering processes that affected (1) metamorphic rocks of probable Belt or pre-Belt age, (2) granodiorite and related rocks of Late Jurassic or Cretaceous age, and (3) Columbia River Basalt of Miocene to Pliocene(?) age. The fourth type is transported clay which occurs in the Latah Formation of Miocene age. Some of the clay in the Latah Formation, however, may be residual.

Clay in Hawaii

A byproduct of other studies by S. H. Patterson in Kauai, Hawaii, has been the discovery of scattered deposits of plastic clay associated with peat deposits in swamps. The clay consists chiefly of halloysite and gibbsite, with minor amounts of iron minerals, titanium minerals, and probably aluminous silica gels. Resources of the clay at 5 localities are estimated at 5 million tons. Much of the clay has a low iron content, but it is likely to have high shrinking and cracking characteristics during drying and firing which would reduce its value for ceramic purposes.

Clay in Maryland

Shale specimens obtained in 1961 by M. M. Knechtel from outcrops of several formations of Paleozoic age in western Maryland have been subjected to bloating tests by H. P. Hamlin, of the U.S. Bureau of Mines, in cooperation with the Maryland Department of Geology, Mines, and Water Resources. When quick-fired in a small electric kiln to temperatures of 2,000° F, 2,100° F, and 2,200° F, specimens of Martinsburg Shale (Ordovician) from a locality in Washington County, Md., formed bloated products comparable in lighteness, strength, and low water-absorption capacity to many rotary-kiln-fired materials that are marketed as lightweight aggregate. The products closely resemble materials reported[7] to have formed when Martinsburg Shale from Frederick County, Va., was fired in a rotary test kiln wherein the temperature fluctuated between 1,925° F and 2,020° F. Shale from the McKenzie Formation (Silurian), exposed at a locality in Allegany County, Md., also gave promising test results, and shale from several other formations in western Maryland expanded enough to suggest that additional sampling and testing might result in discovery of new sources of raw material for rotary-kiln-fired lightweight aggregate. The only such source heretofore reported[8] from Maryland is the St. Marys Formation (Miocene), which crops out in the coastal plain.

REGIONAL AND TOPICAL STUDIES

Mineral deposits in the Piedmont of South Carolina

Investigations by W. C. Overstreet and Henry Bell 3d show that the rocks exposed in the Piedmont of South Carolina represent many grades and types of metamorphism, ranging from upper amphibolite-grade gneiss and plutonic igneous rocks to slightly metamorphosed argillite and tuff intruded by near-surface bodies of granite. This geologic environment is more diverse than implied by the conventional concept that the Piedmont exposes only the deep roots of ancient mountains characterized by high grades of metamorphism. Exceptional regional zoning of mineral deposits is known, and the zones approximately coincide with metamorphic-zone patterns. For example, sheet muscovite, sillimanite, and monazite are found in high-rank metamorphic rocks; kyanite and tungsten minerals are found in intermediate-rank metamorphic rocks; and gold is found in low-rank rocks. These zones

[6] Crider, A. F., 1913, The fire clays and fire clay industries of the Olive Hill and Ashland districts of northeastern Kentucky: Kentucky Geol. Survey, ser. 4, v. 1, pt. 2, p. 592–711.

[7] Calver, J. L., Hamlin, H. P., and Wood, R. S., 1961, Analyses of clay, shale and related materials—northern counties: Virginia Div. Mineral Resources, Mineral Resources Rept. 2, p. 66–67.

[8] Knechtel, M. M., Hosterman, J. W., and Hamlin, H. P., 1960, Bloating clay in Miocene strata of Maryland, New Jersey and Virginia: Art. 29 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B59–B62.

might be better delineated than at present by appropriate methods of regional geochemical and heavy-mineral reconnaissance prospecting.

Beryllium in volcanic rocks

Data collected by D. R. Shawe continue to support the premise that beryllium in Cenozoic volcanic rocks in the western conterminous United States has a markedly provincial distribution. Field and laboratory work by R. R. Coats, P. R. Barnett, and N. M. Conklin has shown that glassy silicic volcanic rocks with abnormal amounts of beryllium (10–30 ppm) occur in two general areas: western Utah-eastern Nevada to southeastern Idaho, and western New Mexico to trans-Pecos Texas–northern Coahuila, Mexico. The only known potentially commercial deposits of beryllium associated with volcanic rocks are in these areas, one at Spor Mountain, Utah (see p. A5), and one in Mexico.[9] It has been known that beryllium deposits generally contain uncommon amounts of fluorine-bearing minerals, and investigations by W. R. Griffiths show that most fluorite deposits in the western conterminous United States lie within the high-beryllium provinces.

Quantitative beryllium determinations

A new laboratory-type analyzer for quantitative beryllium determinations has been designed and constructed by W. W. Vaughn. The counting chamber consists of a moderator and a ring of B^{10} proportional counters, with the sample and Sb^{124} source arranged in a concentric pattern inside the chamber. Initial testing indicates that samples of rock containing as little as a few parts per million of beryllium can be quickly and cheaply analyzed.

Gypsum resources

Resource studies by C. F. Withington of the minable gypsum resources of the United States resulted in an estimate of 50 billion tons of material that average 85 percent gypsum. This represents a supply adequate for many centuries at the current rate of use, and shows that enough raw materials are available to support new uses for this resource.

RADIOACTIVE MATERIALS

DISTRICT AND REGIONAL STUDIES

Colorado Plateau

Most of the uranium deposits in the Ambrosia Lake district, New Mexico, are in two belts that have no recognizable relation to the Ambrosia dome or to the trend of other flexures of post-Dakota age that deform the rocks (Granger and others, 1961). These deposits are older than, and are displaced by, faults that are either the same age or younger than the folds. Other deposits younger than the faults are localized along them. These contain more vanadium and less organic matter and molybdenum than the prefault deposits.

H. C. Granger (Art. 124) and E. S. Santos report that montmorillonite is the dominant clay mineral in the Westwater Canyon Member of the Morrison Formation in samples collected away from uranium deposits in the Ambrosia Lake district, New Mexico, where the Westwater Canyon Member is overlain by the Brushy Basin Member. Within layers of prefault ore, however, chlorite is the principal clay mineral, and the ratio of chlorite to chlorite plus montmorillonite roughly correlates with uranium and carbon contents of the ore. Where the Westwater Canyon Member is truncated and directly overlain by the Dakota Sandstone on the north flank of the Zuni Mountains, the sandstone beds consist of quartz and alkali feldspars in a kaolinite matrix and lack other clay minerals, calcic plagioclase, and iron-bearing minerals. At other nearby places, Leopold[10] and Schlee and Moench (1961) have also noted a kalonite-rich zone in rocks on which the Dakota rests. According to R. H. Moench and H. C. Granger, the origin of the ore deposits at Laguna, N. Mex., and at Ambrosia Lake may be related in some manner to the development of this argillized and leached zone.

Results of geologic studies in the Uravan mineral belt by D. R. Shawe (Art. 62) suggest that warping during deposition of the Salt Wash Member of the Morrison Formation formed a large basin in western Colorado and eastern Utah. In this basin a subsidiary alluvial fan was developed on the much larger fan of the whole Salt Wash Member. The configuration of this subsidiary fan determined the shape and extent of the mineral belt.

From a study of heavy-mineral suites in sandstone beds of the Salt Wash Member of the Morrison Formation, H. E. Bowers and D. R. Shawe (1961) conclude that proximity to mineralized rock in the Disappointment Valley area, Colorado, is indicated by the almost complete absence of black opaque minerals in light-gray carbonaceous sandstone of the ore-bearing unit.

Exploration for uranium deposits in the Moab-Interriver area, Utah, could be improved by use of field analyses for cobalt, according to E. N. Hinrichs. In this area, about three-quarters of the large deposits near the base of the Chinle Formation contain significant amounts of cobalt. A halo of cobalt extends as much

[9] Levinson, A. A., 1962, Beryllium-fluorine mineralization at Aguachile Mountain, Coahuila, Mexico: Am. Mineralogist, v. 47, p. 67–74.

[10] Leopold, L. B., 1943, Climatic character of the interval between the Jurassic and Cretaceous in New Mexico and Arizona: Jour. Geology, v. 51, no. 1, p. 56–62.

as 80 feet into sandstone around at least one deposit. Such a halo could be detected by analyses of drill core or cuttings.

A. T. Miesch (1961b) has shown, from compositional and abundance relations between uranium ore and the altered sandstone lens in which the ore occurs at the Frenchy Incline mine, San Miguel County, Colo., that most of the extrinsic elements in the ore could have been transported from the altered sandstone by either solute diffusion or flowing solutions. The uranium and probably the vanadium, however, could not have been derived entirely from the altered sandstone lens and must have been transported greater distances by flowing solution. Configurations of the ore bodies suggest that solute diffusion played some part in their formation. L. C. Huff and F. G. Lesure (1962) interpret zoned structure in similar deposits in the Salt Wash Member of the Morrison Formation in Montezuma Canyon, Utah, to be the result of diffusion transport of metals just prior to their deposition.

Shirley Basin, Wyoming

Major uranium deposits in the Shirley Basin, Wyo., are in a well-defined mineral belt and are mainly along the curved margins of an extensive interface between altered sand and the enclosing unaltered sand, according to E. N. Harshman (Art. 122). The altered sand is greenish yellow and contains nontronite clay and altered, incoherent, coalified plant debris. Pyrite, magnetite, and ilmenite, once present in the sand, have been almost completely destroyed. In contrast, the surrounding unaltered sand is gray and contains montmorillonite, unaltered, coherent, coalified plant debris, pyrite, magnetite, and ilmenite. Geochemistry of the alteration is not fully understood, but the alteration is thought to be directly related to deposition of uranium. Association of ore with altered sand makes the altered sand an excellent exploration guide.

Migration of uranium in the Hulett Creek area, Wyoming

C. S. Robinson and J. N. Rosholt interpret radiochemical and other analyses of samples from uranium deposits in the Hulett Creek area, Wyoming, as indicating that the deposits have had a complex history in the last 250,000 years (Rosholt, 1961, and Robinson and Rosholt, 1961). Those deposits above the water table were formed more than 250,000 years ago but underwent oxidation, migration of uranium, and some secondary enrichment between 80,000 and 10,000 years ago. In equally old deposits at the water table these processes have continued to the present. In deposits below the water table uranium began to accumulate about 180,000 years ago and has continued nearly to the present even though some of the uranium has remained in these deposits only temporarily.

Mount Spokane area, Washington

Geologic mapping by A. E. Weissenborn has shown that there are two principal units of intrusive rock in the Mount Spokane quadrangle, Washington. Uranium deposits are confined to muscovite-rich quartz monzonite, the less abundant unit, which contains numerous pegmatites and appears to be a metasomatic replacement of the more abundant biotite-rich quartz monzonite.

Thorium veins in the Wet Mountains, Colorado

Dikes of mafic lamprophyre and glassy rhyolite that are closely associated with thorium-bearing veins in the Wet Mountains, Colo., and are involved in the wallrock alteration of the veins are probably of Tertiary age, according to George Phair and F. G. Fischer. The dikes are older than the ore and are chemically, mineralogically, and texturally indistinguishable from similar dikes that cut volcanic rocks of Tertiary age in the Mount Tyndall area. Furthermore, the abundance of lead isotopes in galena from the thorium-bearing veins is similar to that of leads from deposits of known Tertiary age (Phair and Mela [11]) in the Front Range and is markedly different from leads of known Precambrian age. These relations suggest that the thorium deposits are Tertiary in age and indicate a need for a revision in thought concerning what constitutes favorable ground for thorium prospecting in this general area.

Some of the thorium-bearing veins in the Wet Mountains area contain 0.3 percent niobium, and the altered zone adjacent to the Antrim vein contains as much as 0.5 percent.

Uranothorite in the Hailey area, Idaho

D. L. Schmidt has determined that uranothorite is commonly a sparsely distributed accessory mineral in a large mass of intrusive granodiorite of the Idaho batholith near Hailey, Idaho, but in detail much of the uranothorite is in local segregations a few feet across. Uranothorite is 10 to 1,000 times as abundant in the segregations as it is in the bulk of the rock, yet the segregations are otherwise indistinguishable from adjacent rock. The segregations were formed during late or postmagmatic endomorphic alteration that released an estimated 1 percent of the thorium initially held in other positions in the rock to crystallize as uranothorite. Potentially economic placer deposits of uranothorite occur downstream from places where the segregations are most numerous.

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[11] Phair, George, and Mela, Henry, Jr., 1956, The isotopic variation of common lead in galena from the Front Range [Colo.] and its geological significance: Am. Jour. Sci., v. 254, no. 7, p. 420–428.

TOPICAL STUDIES

Uranium in marine black shales

The results of many investigations of uranium in marine black shales by the Geological Survey have been reviewed and interpreted by V. E. Swanson (1961). Besides pointing out the greater potential economic significance of the Chattanooga Shale, more completely documented by Conant and Swanson (1961), as compared to any other domestic uraniferous marine black shale, the author arrives at carefully reasoned, though tentative, conclusions. Chief among these are (1) sea water that contained only about 3 parts per billion uranium, like modern sea water, was the source; (2) uranium was collected partly by humic materials preserved in a reducing bottom environment and partly by precipitation by H_2S evolved from decaying organic remains in this environment; and (3) in some similar environments where pH was between 7.5 and 8.0, phosphorite also was precipitated and uranium was preferentially fixed in the phosphatic particles rather than in the surrounding black muds.

Monazite in crystalline rocks

A review of the literature by W. C. Overstreet shows that most reported occurrences of monazite in crystalline rocks are in rocks of Precambrian age. This distribution reflects mainly the greater proportion of high-grade metamorphic and plutonic rocks, favored hosts of monazite, in Precambrian terranes than in younger parts of the crust (Overstreet[12]). Rocks petrologically favorable as hosts for monazite are monazite bearing regardless of age, and petrologically unfavorable rocks of Precambrian age are as lean in monazite as are similar rocks of younger age.

FUELS

Many studies carried on within the Geological Survey contribute information useful to those engaged in the search for organic fuels. This information includes the results of fundamental studies of regional geology and stratigraphy reported under the regional headings starting on page A12, and the reports on studies of processes and principles starting on page A73. Only studies pertaining to fuels or areas of fuel resources are reported here.

BIBLIOGRAPHY OF ENERGY RESOURCES

An annotated bibliography of selected sources of information on domestic and world energy resources by James Trumbull (1961) summarizes many publications relating to resources and productive capacity of coal, petroleum and natural gas, and oil shale in the United States.

PETROLEUM AND NATURAL GAS

Future petroleum-producing capacity

As a result of a study of the data available, A. D. Zapp (1962) concludes that the factors contributing to the rate of growth in the petroleum-producing capacity of the United States in the years following World War II are the only realistic factors usable for future producing-capacity predictions. The quantity of undiscovered oil is large, but the rate of increase of producing capacity will be dependent primarily on economic incentives that encourage exploration.

Oil and gas map of New Mexico

A map prepared in cooperation with the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources, shows the extent of petroleum and natural-gas exploration and development in New Mexico. The map, compiled by Sophie Vlissides and R. A. Bieberman (1961), shows the location of oil and gas fields, pipelines, and dry holes. Stratigraphic sections in four parts of the State are also included on the map.

Oil-producing potential in the Salinas Valley, California

D. L. Durham reports that potential oil-producing folds in the area of the Salinas Valley, Monterey County, Calif., may be confined to the fault blocks. Mapping on the west side of the valley has shown that most of the folds in the Monterey Shale are in fault blocks and are not folds that have been offset by faulting.

COAL

Coal reserves of Washington

The Geological Survey's program to estimate the coal reserves of the United States, which has been summarized by Paul Averitt (1961), was advanced during the year by the publication of a new estimate of the coal reserves for the State of Washington. This report, prepared by H. M. Beikman, H. D. Gower, and T. A. Dana (1961) in cooperation with the State of Washington, indicates that an estimated 6 billion tons of coal reserves remained in the ground as of January 1, 1960. Most of this coal is bituminous and some of it has coking qualities. The estimate is conservative because large areas underlain by coal-bearing rocks have not been mapped in sufficient detail to permit accurate coal-reserve estimates.

Coal fields of Alaska

A new map of the coal fields of Alaska prepared by F. F. Barnes[13] shows, on a scale of 1:5,000,000, the dis-

[12] Overstreet, W. C., 1960, Metamorphic grade and the abundance of ThO_2 in monazite: Art. 27 *in* U.S. Geol. Survey Prof. Paper 400–B. p. B55–B57.

[13] Barnes, F. F., 1961, Coal fields of the United States, sheet 2—Alaska: U.S. Geol. Survey.

tribution of coal-bearing areas according to the rank of coal. Insert maps and diagrams show the age of coal-bearing formations in the State, the basis of rank classification, the original reserves, and production up to January 1, 1959, of the various coal fields.

Coal-rank studies in Alaska

Variation in the rank of coals of Tertiary age in the Cook Inlet basin, Alaska, has been studied by F. F. Barnes (Art. 65). Evidence indicates that age, depth of burial, and regional metamorphism have been factors in advancing the rank of the coal in parts of that area but that no single factor was dominant for the whole area.

Coal resources of specific coal fields

In a recently published report on the geology and fuel resources of the Orderville-Glendale area, Kane County, Utah, W. B. Cashion (1961a) estimates that the original reserves of high-volatile C bituminous coal in the area totaled about 3.5 billion short tons.

R. B. Johnson (1961a) reports that coal beds of Late Cretaceous and early Tertiary age in the Trinidad coal field of southern Colorado contain an estimated 16,367 million short tons of nonagglomerating high-volatile C and agglomerating high-volatile A and B bituminous coal. Production up to 1957 was at least 217 million short tons.

Field studies by F. F. Barnes in the southern part of the Beluga-Yentna district, Alaska, have shown that coal beds 10 to 50 feet thick are exposed at many places within a 125-square-mile area and may extend into a much larger area. The coals range in rank from lignite to subbituminous and in age from Miocene to middle Oligocene.

OIL SHALE

Studies of outcrops and cored sections by W. C. Culbertson have shown that the Tipton Shale Member of the Green River Formation is continuous and uniform over a large area in the southern part of the Green River basin, Sweetwater County, Wyo. Using assay data by the U.S. Bureau of Mines, he estimates that the top 43 feet of the Tipton has a potential oil yield ranging from 15 to 30 gallons of oil per ton under an area of about 1,400 square miles, for a total potential oil yield of about 60 billion barrels of oil.

Recent work by W. B. Cashion has led to a better understanding of the geometry of the gilsonite veins in the Uinta basin and has shown a relation between the width of the vein and the thickness of the sandstone beds in the wallrock. These factors have allowed a more refined estimate of the gilsonite reserves. Indicated reserves of gilsonite in veins having estimated maximum depths ranging from 200 to 1,300 feet and lying between long. 109° and 109°15′ W. in the basin are about 30 million tons.

WATER

WATER USE

Estimated use of water in the United States, 1960

In 1960 almost 270,000 million gallons of water per day, not including the amount of water used to develop waterpower, was used in the United States according to K. A. MacKichan and J. C. Kammerer (1961); an additional 2,000,000 mgd was used to develop waterpower. Of the 270,000 mgd withdrawn, only 61,000 mgd was discharged to the atmosphere or incorporated into products. About 220,000 mgd was taken from surface-water sources and 47,000 mgd from ground-water sources.

Public water-supply systems served about 136 million people an average of 151 gallons per day per person. Rural use of water totaled about 3,600 mgd, of which 1,600 mgd was for livestock and 2,000 mgd was for domestic use. Water was withdrawn for irrigation at the rate of 110,000 mgd to irrigate 39 million acres, including 23,000 mgd lost in conveyance between the points of diversion and use. Industry used an average of 140,000 mgd of self-supplied water, including 100,000 mgd for thermoelectric power.

Since 1955 the use of saline water has doubled, the amount of water used for generation of electric power has increased 33 percent, and the withdrawal of water for uses other than electric power has increased 12 percent.

Petroleum industry

Petroleum refineries required about 3,500 mgd of water in 1955, or about 3 percent of the total estimated daily withdrawal of water by industry in the United States. These estimates are based on a survey by L. E. Otts of 61 various-sized refineries throughout the Nation. About 91 percent of the water withdrawn was for cooling. One-third of the refineries reused their cooling water from 1 to more than 50 times. Refineries with recirculating cooling systems consumed about 24 times more water per barrel of charge than refineries using once-through cooling systems, but withdraw about 25 times less makeup water.

The refining of a barrel of crude oil requires an average of 468 gallons of water; the range was from 6.5 to 3,240 gallons and the median was 95 gallons of water per barrel of crude oil. Noncracking refineries used an average of 375 gallons of water per barrel of crude oil and refineries with cracking facilities required an average of 471 gallons per barrel. The water requirements of refinery processing units varied from about 125 gallons per barrel for polymerization and alkylation units to 15.5 gallons per barrel for distillation units.

Surface-water sources provided 86 percent of the water demand and reprocessed municipal sewage provided less than 1 percent.

Mining and beneficiation of iron ore

About 2,150 million gallons of water was used in mining iron ore and 166,000 million gallons was used at iron-ore beneficiation plants during 1956 according to O. D. Mussey.[14] About 50 percent of the water used in mining iron ore was consumed, and about 2 percent of the water used in concentrating iron ore was consumed; therefore, about 4,400 million gallons of water was consumed in these operations. In mining and beneficiating iron ore, about 1,700 gallons of water was required per ton of iron concentrates or direct smelting ore. Mussey estimates that the water used for mining and beneficiating iron ore will increase 65 percent during the period 1956 to 1980.

Annotated bibliography of water use

An annotated bibliography of water-use data, by States, for 1960 was prepared by Lois E. Randall (1961).

Water resources of Providence, Rhode Island, and vicinity

In 1954 public water-supply systems in the Providence, R.I., area furnished an average of 66 mgd to a population of 648,000. According to H. N. Halberg, C. E. Knox, and F. H. Pauszek (1961), about 61 mgd was obtained from surface water and 5.5 mgd from ground water. About 52 percent of the water furnished by the public supply system was used by industry, 42 percent was used for domestic purposes, and 6 percent was used by municipal governments or was lost by leakage. Industry also withdrew 7.5 mgd of ground water and 35 mgd of fresh surface water from private sources exclusive of water withdrawn for water power (356 mgd of saline water for condensing water for thermoelectric-power production). About 0.9 mgd, obtained from privately-owned sources, was used for domestic supplies by 18,000 people.

Water resources of the Utica-Rome area, New York

Municipal water systems supplied about 57 percent of the 48.5 mgd used in 1954 in the Utica-Rome area, New York, according to H. N. Halberg, O. P. Hunt, and F. H. Pauszek.[15] Of the 27.4 mgd furnished by public water supplies, about 35 percent was supplied to industry, about 43 percent was for domestic use, and the remaining 22 percent was for all other uses. More than 99 percent of the total of 29.1 mgd used by industry was obtained from surface sources. The larger users of industrial water were producers of metal, paper, and textile products. The small amount of ground water (0.2 mgd) withdrawn for industrial use was from private wells and was principally for light industrial operations such as bottling plants. Water was used for miscellaneous agricultural purposes, irrigation, and domestic use on farms at an average rate of 0.8 mgd. About 6.2 million gallons was used for irrigation during the year. Based on an estimated per-capita consumption of 65 gallons per day, the 15,700 people living outside areas served by public water supplies used about 1 mgd of water.

Water resources of Tacoma, Washington, and vicinity

Public water supplies in the Tacoma, Wash., area withdrew an average of 70.1 mgd in 1955 to serve an estimated population of 290,000 people. According to W. C. Griffin, J. E. Sceva, H. A. Swenson, and M. J. Mundorff (1962), about 70 percent of the water was withdrawn from streams. Industry withdrew an average of about 27 mgd from wells and about 20 mgd from surface-water supplies. Rural families in this area used between 180 to 225 gpd for domestic use. The total rural demand for domestic and livestock use ranged from 2.2 to 3.6 mgd. The average annual use of water for irrigation in the area probably does not exceed 20 mgd.

Irrigation in New Mexico

W. C. Ballance and others (1962) estimate that 860,000 acres was irrigated in New Mexico in 1960, of which 440,000 acres was irrigated with ground water and 130,000 acres was irrigated with a combination of ground water and surface water. About 1,070,000 acre-feet of ground water was applied in 1960, about 85,000 acre-feet less in 1959.

The above-average precipitation in the eastern part of the State in 1960 reduced the demand on ground water for irrigation. Water levels declined as much as 14 feet in parts of the Roswell basin in 1959 but rose as much as 10 feet in the same area in 1960. Water levels declined in 1959 throughout the irrigated area in Quay County, whereas in 1960 rises were noted in most of the area. Water-level changes in Roosevelt and Lea Counties were similar to the Roswell basin in that large areas of water-level rise were noted in 1960 in areas where declines occurred in 1959.

The precipitation in the western part of the State was below average in 1960, resulting in increased pumpage of ground water for irrigation with the result that ground-water levels in that part of the State reached record lows.

REGIONAL GEOLOGY AND HYDROLOGY

A principal mission of the Geological Survey is to increase our knowledge of the regional geology of the

[14] Mussey, O. D., 1961, Water—its role in mining and beneficiating iron ore: New York, Am. Inst. Mining Metall. Engineers, Soc. Mining Engineers Preprint 61H81.

[15] Halberg, H. N., Hunt, O. P., and Pauszek, F. H., 1962, water resources of the Utica-Roma area, New York: U.S. Geol. Survey Water-Supply Paper 1499–C. (In press.)

United States. The more we know about the composition, age, physical properties, origin, and distribution of the countless rock units of the Nation, the more readily and cheaply can we direct geology to the service of mankind. The preceding pages contain numerous examples of the application of geology to human needs in the fields of mineral and water resources, and it is reasonable to assume from past experience that new uses of geologic knowledge will continue to be found as long as man lives on and derives his sustenance from the earth. All these applications are dependent, for their successful use, on some prior knowledge of the geology of specific areas. Study of geologic maps, for example, may show that an Area A contains the same sort of association of rocks as is found at a major ore deposit, which makes it a likely spot to test various exploration techniques. Prior studies of the geology of the region around an Area B may provide the starting point for site selection and subsequent detailed geologic studies for a major engineering project. An existing geologic map could suggest that certain sandstone beds that crop out in an Area C may be valuable aquifers at shallow depth farther east. Regional geologic studies, therefore, are most effective when the work is done and the results are available before need for them arises.

Some of the regional geologic and geophysical mapping carried on by the Geological Survey is directly related to specific resources or engineering investigations, but a far greater part is conducted with the immediate aim of upgrading our knowledge of the regional geology of the United States in anticipation of future need. In the pages immediately following, no attempt is made to record all the areas in which regional geologic and geophysical investigations have been carried on (for a list of these, see p. A137 to A168), but these pages, instead, report only some of the more significant additions to our knowledge of the geology of specific areas or regions.

Studies of the quality, quantity, and availability of surface and ground water are largely by specific area, generally counties, districts, regions, or drainage basins. These studies include the various aspects of the geologic and hydrologic environment that relate to the occurrence and movement of water on the surface and underground. Such studies stress evaluation of sources of water, determination of how it occurs in the area, its chemical and physical composition, computation of the quantity of water available for use, description of its direction and rates of movement, evaluation of fluctuations in flow, and determination of disposition of the water supply as use or waste in the area or outflow from the area.

Results of regional geologic and hydrologic studies are classified in the following sections according to the subdivision of the conterminous United States shown on figure 1.

SYNTHESIS OF GEOLOGIC DATA ON MAPS OF LARGE REGIONS

Compilation of geologic maps of large regions or of national scope continued as a small but important function of the Geological Survey. Such maps depend on data from mapping and topical studies by Geological Survey personnel, on published data, and on unpublished data generously provided by State geological surveys, private companies, and universities. Some maps of this type are prepared, and in some instances published, by the Geological Survey in collaboration with national and international scientific organizations. Collaborative maps nearing completion include:

1. Geologic map of North America, scale 1:5,000,000. This map is being compiled by a committee of the Geological Society of America, E. N. Goddard, University of Michigan, chairman.
2. Basement-rock map of North America from lat 20°–60° N. scale, 1:5,000,000. This map is being compiled by a committee of the American Association of Petroleum Geologists, P. T. Flawn, University of Texas, Bureau of Economic Geology, chairman.
3. Absolute-gravity map of the United States, scale 1:2,500,000. This map is being compiled by the American Geophysical Union Committee for Geophysical and Geological Study of the Continents, G. P. Woollard, University of Wisconsin, chairman. A preliminary compilation of maps for each of the 48 conterminous states is nearly complete; these maps will be used to prepare the published version of the gravity map of the United States.
4. Tectonic map of North America. This map is being compiled for the Subcommission for the Tectonic Map of the World, International Geological Congress, under the direction of P. B. King.

Collaborative maps published during the year or nearing completion are described below.

Mineral-occurrence maps of the conterminous United States

A group of 20 mineral-occurrence maps that show the location of important metallic and nonmetallic mineral-producing areas in the conterminous United States has been published in the Mineral Resources series of the Geological Survey (MR–13 through MR–31, and MR–33). The project was under the joint direction of P. W. Guild, serving as Vice President for North America of the Subcommission for the Metallogenic Map of the World, International Geological Congress, and W. L. Newman.

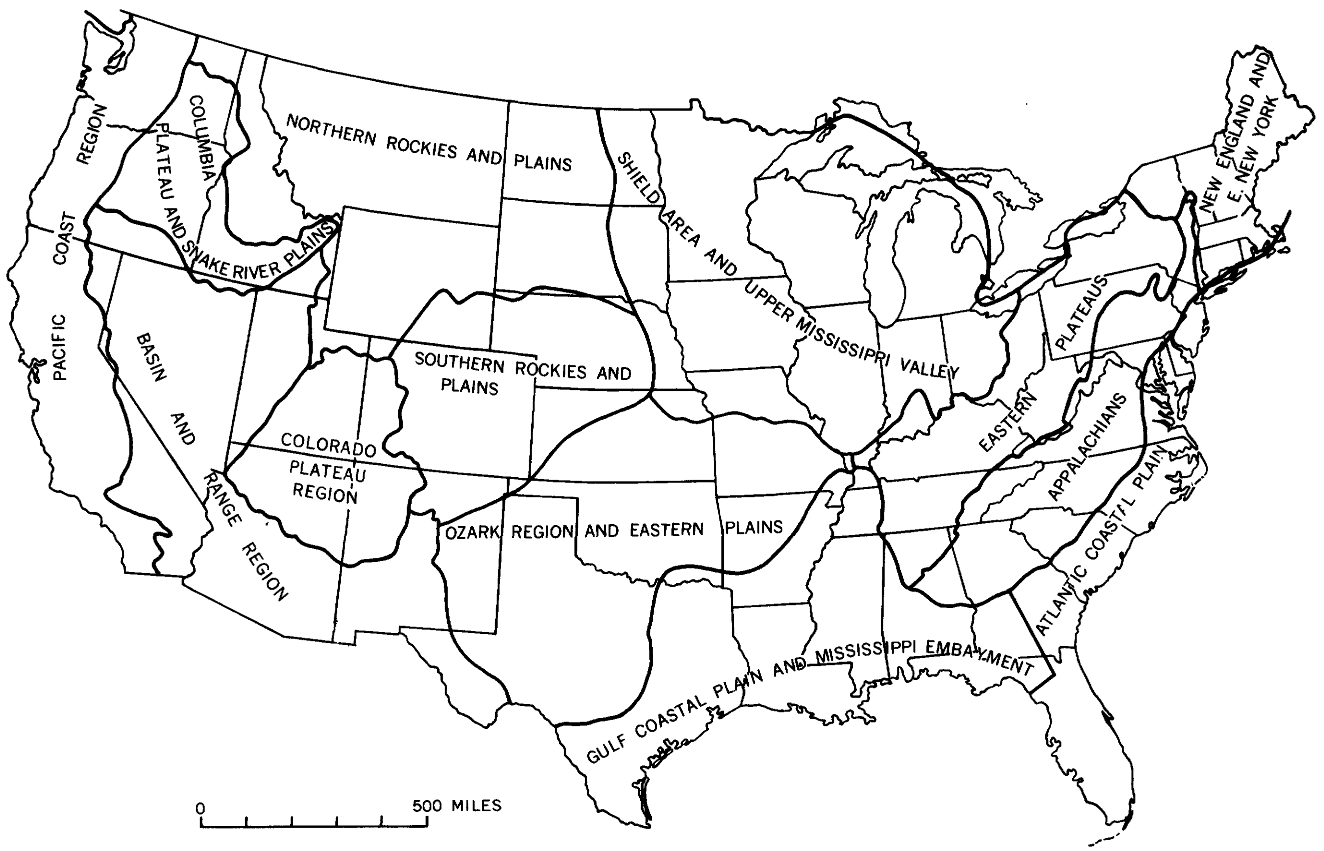

FIGURE 1.—Index map of the conterminous United States showing boundaries of regions referred to on accompanying pages.

The maps are at a scale of 1:3,168,000, and each is accompanied by a short text that describes the geologic occurrence of the mineral commodity and identifies each location by name and cites published references to it. The mineral commodities include copper, vanadium, lead, uranium, zinc, antimony, gold, tungsten, mercury, chromite, bismuth, thorium and rare earths, titanium, borates, pyrophyllite and kyanite, manganese, asbestos, magnesite and brucite, gypsum and anhydrite, and talc and soapstone. Maps of about a dozen more mineral commodities are in various stages of preparation.

The work is being expanded to include mineral occurrences throughout North America in cooperation with Canadian and Mexican counterpart organizations under the general program of the Subcommission for the Metallogenic Map of the World, International Geological Congress.

Mineral-occurrence maps of Alaska

A map showing the location of lode gold and silver occurrences in Alaska has been prepared by E. H. Cobb (1962). This map is the fifth of a series of mineral-occurrence maps of Alaska (scale, 1:2,500,000) to be published in the MR series. Previously published maps in this series locate occurrences of chromite, cobalt, nickel, platinum, copper, lead, zinc, molybdenum, tin, tungsten, antimony, bismuth, and mercury. This series, as well as the mineral-occurrence map series in the conterminous United States, may serve as the basis for testing regional metallogenic concepts.

Tectonic map of the United States

The new tectonic map of the United States, on a scale of 1:2,500,000, was published by the U. S. Geological Survey in January 1962. The map was prepared as a joint project of the American Association of Petroleum Geologists and the Geological Survey under the direction of G. V. Cohee.

The map is a complete revision of the tectonic map published by the Association in 1944 and shows many additional features. It is of special interest in the search for petroleum, natural gas, and ore deposits, for it provides a geologic and tectonic framework for the delineation of major mineral provinces.

Paleotectonic-map folios

The long-term program to produce paleotectonic-map folios of national scope for each of the geologic systems is continuing. The folio for the Permian System has been compiled and is being edited prior to publication. This folio focuses attention on prominent transverse trends of major tectonic elements in the conterminous United States during late Paleozoic time. The longest and most conspicuous structural features, including both positive and negative belts, trend northeast. Shorter, less prominent northwest-trending structures may represent offsets or jogs in the major northeast trends. These structural belts apparently controlled transgressions and regressions of the sea, the location of evaporite basins, and the distribution of detrital materials.

Work on the folio for the Pennsylvanian System has been confined mainly to data compilation. With the intent of accelerating production of the paleotectonic folios, preliminary work on the Mississippian System was started in 1962.

Tectonic setting of uranium deposits in the Cordilleran foreland

F. W. Osterwald and B. G. Dean (1961) relate the position of uranium deposits to large-scale tectonic features and many small structures in the central part of the Cordilleran foreland northward from central Colorado. Their portrayal and synthesis of a large amount of tectonic and structural data also provide a framework for analyzing distribution of other mineral commodities in the region.

SYNTHESIS OF HYDROLOGIC DATA FOR LARGE REGIONS

The synthesis of hydrologic data for the entire United States, for North America, and for the world is a continuing function of the Geological Survey. The bulk of the data is either gathered in the program for collection of basic hydrologic records throughout the Nation, collected as part of local and regional investigations of hydrologic conditions, or compiled from sources outside the Geological Survey.

Reports containing much of these data are published in one of the following U.S. Geological Survey Water-Supply Paper series:

"Surface Water Supply of the United States"
"Ground-Water Levels in the United States"
"Quality of Surface Waters of the United States"

The first two are published at 5-year intervals and the last is published annually.

Additional interpretive and descriptive studies are listed under separate headings below.

Thermal springs of the world

A report by G. A. Waring on the thermal springs of the world is being prepared for publication. Information on the location of thermal springs, water temperature, rate of flow, chemical character of the evolved gases, and the uses of the water will be tabulated by countries or other geographic areas. Brief descriptions of the geologic setting and maps showing location of the springs will accompany the tabulations. An extensive bibliography including annotated references to the literature on thermal springs is planned.

Ground water in the United States

A report on the ground-water situation in the United States, prepared in a draft for the President's Water Resources Policy Commission and published in 1951 as Geological Survey Circular 114, is being brought up to date by C. L. McGuinness. The report will review, region by region and State by State, the ground-water situation, problems, and prospects for the future. This review is timely because of the increased awareness of water problems, as recognized during the past few years by the establishment of a number of governmental commissions and committees to study and recommend solutions to present and anticipated water problems.

Descriptions of the hydrologic cycle and the ground-water regions of the United States will be accompanied by descriptions of the occurrence, availability, quality, and use of ground water in each of the 50 States.

Flood frequency in the United States

Nationwide reports of flood frequency are being prepared in cooperation with numerous State and local agencies. The reports describe the frequency of floods at selected stream-gaging stations and extend the data to ungaged sites on major and minor streams. Recurrence intervals for annual floods and the mean annual flood (a flood having a recurrence interval of 2.33 years) are calculated for the gaging stations. Definition of the relation between the mean annual flood and drainage-basin characteristics enable the mean annual flood to be predicted at any point in the drainage basin. The reports will be published in the Water-Supply Paper series in several parts corresponding to the drainage-basin subdivisions used in "Surface Water Supply of the United States."

Chemical quality of river water in the conterminous United States

Three maps showing (1) prevalent dissolved solids and concentrations, (2) prevalent chemical type, and (3) mean annual discharge-weighted sediment concentration of rivers in the conterminous United States are being prepared by F. H. Rainwater. These maps, which will be published as a Geological Survey Hydrologic Atlas, should be useful to the water consumer, the administrator, the scientist who is not a specialist in this field, and to people who are searching for general information on water.

NEW ENGLAND AND EASTERN NEW YORK REGION

Cooperative geologic-mapping programs are presently being carried on with the Commonwealth of Massachusetts and with the States of Rhode Island and Connecticut. Geophysical and geochemical surveys, and field studies related to mineral deposits, are in progress in these States and in Maine, Vermont, and New Hampshire. Water-resources investigations in New England and New York are carried on largely through cooperative agreements with the various States.

Results of geologic and hydrologic studies in this area are summarized below. Other information pertaining directly to New England and easter New York may be found on other pages as follows: water resources of Providence, R.I., page A12; marine geology, page A79; electrical properties of the earth's crust, page A82; coastal erosion, page A106; and geochemical prospecting in Maine, page A121.

Geologic and geophysical studies in Maine

The Ordovician succession in Maine is now known to contain rocks ranging in age from the lower middle part of the Ordovician System (Llanvirn) through the upper part (Ashgill), according to studies made by R. B. Neuman, in cooperation with several university paleontologists. Although the sequence is not complete in any one section, it can be pieced together from several areas. The oldest fossiliferous rocks, in the Shin Pond area, are now considered to be early Middle Ordovician (Llanvirn). Later Middle Ordovician rocks with shelly faunas include the Kennebec Formation of Boucot [16] of the Moosehead Lake region; sandstone and conglomerate of the Spider Lake quadrangle, discovered by Bradford Hall, of Yale University, and the "ribbon rock" of Aroostook County near Fort Fairfield, in which brachiopods were found by W. H. Forbes, of Washburn. Graptolites, conodonts, and radiolaria associated with these rocks are being studied. Trilobites and brachiopods in Ordovician rocks of the Presque Isle quadrangle are of Late Ordovician (Ashgill) age.

A major fault, which probably originated in Devonian time, was mapped by R. H. Moench in the Phillips quadrangle. The fault strikes about N. 70° E. and dips steeply north. Displaced rock units and metamorphic zones indicate an apparent right-lateral offset of about 1 mile, but most observed slickenside striae are oriented downdip, suggesting that some dip-slip movement took place.

Most of the Greenville quadrangle is underlain by two sedimentary units of probable Silurian or Early Devonian age, according to G. H. Espenshade and E. L. Boudette. In the absence of usable fossils, widespread graded bedding has provided the key to structural and stratigraphic relations. A differentiated mafic intrusion extends northeasterly for about 10 miles across the northern part of the quadrangle and is part of a large intrusion that may be as much as 53 miles long. Age determinations by Henry Faul on biotite from the gabbro and a nearby granitic intrusion indicate Early Devonian ages.

A broad belt containing conductive black slates was traced by E. B. Ekren and F. C. Frischknecht from the Smyrna Mills quadrangle across the Island Falls quadrangle and into the Sherman and Shin Pond quadrangles by electromagnetic methods. The largest electromagnetic anomaly in the Island Falls quadrangle is caused by a distinctive unit of interbedded black chert and slate containing graptolites of Middle Ordovician age. Similar conductive rocks containing the same fossils have been found in the Danforth and Howe Brook quadrangles.

Geologic and geophysical studies in Massachusetts

E-an Zen, in a long-term field study of the Taconic sequence, is comparing the stratigraphic and structural relations of the Taconic sequence at its south end in northwestern Connecticut with those at the north end in west-central Vermont. Results to date suggest that the northern and southern areas are underlain by two different sequences of argillite and carbonate rock. An argillite sequence of the "high Taconics" in western Massachusetts is of obscure age and structural relation to a surrounding carbonate sequence. New data on the carbonate sequence indicate the similarity of sedimentary conditions in Middle Ordovician time and continuity of the Middle Ordovician unconformity between central Vermont and southwestern Massachusetts.

N. P. Cuppels has mapped a quartzo-feldspathic unit of the Marlboro Formation in the Concord quadrange that is similar in lithology to a facies of the Newbury Formation mapped by R. O. Castle in the Salem quadrangle to the northeast.

R. N. Oldale mapped the distribution of unmetamorphosed red arkose and shale fragments in the Pleistocene deposits of the Salem quadrangle (Art. 71). This material closely resembles the Triassic sedimentary rocks of the Connecticut Valley and may indicate the presence of previously unknown Triassic bedrock in northeastern Massachusetts. The high concentration of arkose and shale in the drift in the northwestern part of the quadrangle suggests that the bedrock source is nearby, presumably concealed by drift.

A hitherto unknown small inlier of granite in the Pennsylvanian sedimentary rocks of the Narragansett Basin was discovered near Attleboro by J. P. Schafer.

[16] Boucot, A. J., 1961, Stratigraphy of the Moose River synclinorium, Maine: U.S. Geol. Survey Bull., 1111–E, p. 153–188.

The inlier is bounded on one side by a fault and on the other by a nearly vertical disconformity.

Deep drilling in Harwich on Cape Cod, done by the Raytheon Co. under contract to the Air Force Cambridge Research Laboratory, and logged and interpreted by Carl Koteff and John Cotton, has revealed 435 feet of Pleistocene deposits consisting of 160 feet of fine sand, 153 feet of bluish-gray silt, 116 feet of bouldery till, and a 6-foot iron-stained zone that may be the base of the till. The rock below this, penetrated to 565 feet below the iron-stained zone, is gray sericitized phylitic schist. The bedrock is of unknown age, but it is lithologically similar to both the Rhode Island Formation of Pennsylvanian age and the Blackstone Series of Precambrian(?) age. A second 1,000-foot drill hole in nearby Brewster revealed 433 feet of Pleistocene deposits overlying granite gneiss, samples of which have been taken for age determination.

Although the paleontologic work on Upper Cretaceous and Tertiary sediments of western Martha's Vineyard has not been completed, C. A. Kaye is able to present a tentative stratigraphic section. Both the Raritan and Magothy Formations are probably present. A recently discovered greensand may belong to the upper part of the Magothy Formation, the Matawan Group, or the Monmouth Group. The distribution of fossiliferous glauconitic and ferruginous sands of probable Matawan age in the drift gives a general idea of the former outcrop of these beds and indicates a northeast strike of the coastal plain sediments. As yet there is no paleontologic evidence of Eocene sediments. Recent potassium-argon dating of a tektite found on the surface at Gay Head [17] indicates a late Eocene or early Oligocene age for the glass. This does not necessarily mean that deposits of that age are present. The Miocene is represented by a richly fossiliferous greensand whose exact position in the Miocene has not yet been determined. Above the Miocene greensand is a sulfide-rich, somewhat glauconitic clay in which no fossils have yet been found. It may be Pliocene, and may be the source of several Pliocene vertebrate fossils that have been found at Gay Head.

In companion studies, good correlation between mineralogy and stratigraphy has been found in the Gay Head cliffs of Martha's Vineyard by J. C. Hathaway. Where both Tertiary and Pleistocene sediments are glauconitic, they can be distinguished by the presence of chlorite and a higher content of mixed-layer mica-montmorillonite in the Tertiary and the near absence of these minerals in the Pleistocene. Of the nonglauconitic deposits in the cliffs, the Cretaceous deposits are characterized by abundant kaolinite, the Tertiary by chlorite, mica, and mixed-layer mica-montmorillonite, but little or no feldspar; and the Pleistocene by the same assemblage as the Tertiary, but with abundant feldspar. Electron-microscope study of phosphate nodules from the Miocene of the cliffs showed significant amounts of organic materials, abundant diatom fragments, and a wide range in particle size of apatite. These findings suggest that the nodules originated as fecal material, perhaps from small whales, whose fossil remains are common in these beds.

The Pleistocene stratigraphic section of western Martha's Vineyard, according to C. A. Kaye, consists of 6 tills and 3 units of sorted sediments. The oldest deposit is a till made up almost entirely of rock detritus from Coastal Plain sediments and is thought to belong to the Nebraskan Glaciation. A littoral marine unit above this comprises three sedimentary facies and is placed in the Aftonian Interglaciation. This unit probably correlates with the fossil-bearing sediments on Long Island that have been called the Gardiners Clay and with the shell-bearing beds of Sankaty Head, Nantucket. The section contains three stratigraphically distinct clays. Besides the Nebraskan and Aftonian, the following stratigraphic subdivisions of the Pleistocene are thought to be present: Kansan, Yarmouth(?), Illinoian, and Wisconsin (Farmdale(?), Iowan, and Tazewell).

Studies of surficial deposits in the Rowe and Heath quadrangles by J. H. Hartshorn have shown that the steep and narrow Deerfield River valley was filled with proglacial outwash to a height of approximately 80 feet above the present stream gradient. The outwash has been extensively reworked and terraced by late-glacial and postglacial stream erosion and in numerous places 4 to 6 terraces occur in flights. A group of high kame deposits at different altitudes above the cut terraces provide evidence of a series of glacial lakes that were probably held in by ice dams, and of kame terraces graded to now-vanished base levels on a glacier tongue.

R. B. Colton and R. V. Cushman (1962) have mapped numerous narrow bodies of gravel and sand flanking till hills and drumlins in the Connecticut River valley between Hartford, Conn., and Springfield, Mass. Most of these deposits project beyond the southern ends of the hills as southwestward-curving "tails." They are interpreted as beach deposits formed at or below the highest strand line of glacial Lake Hartford. This strand line now rises northward about 4 feet per mile because of postglacial tilting.

Evidence of late-glacial and early post-glacial eolian activity in Massachusetts is provided by a very widespread surface layer of windblown sand and silt, by

[17] Kaye, C. A., Schnetzler, C. C., and Chase, J. N., 1961, A tektite from Gay Head, Martha's Vineyard, Massachusetts: Geol. Soc. America Bull., v. 72, no. 2, p. 339–340.

ventifacts in this material, by wind-abraded surfaces on a few bedrock outcrops, and by stabilized sand dunes. J. H. Hartshorn (1962) reports that fluted bedrock surfaces at six localities in eastern Massachusetts were cut during late-glacial time by winds mostly from the north to northeast.

C. R. Tuttle (1962), in connection with seismic investigations done in cooperation with the Massachusetts Department of Public Works, has described a seismic layer with a compressional-wave speed of 5,000–8,000 feet per second, which he calls high-speed till. It is ordinarily found beneath a surface layer of till in which the speed is 2,000–4,500 feet per second. The seismic speeds obtained in this work must be used with caution as indicators of lithology, because high-speed materials interpreted as till have proved in a few places to be sheared phyllite, fracture-cleaved siltstone, or granodiorite containing unconsolidated clastic dikes.

E. A. Sammel (1962b), mapping surficial deposits in connection with ground-water investigations in the Ipswich, Newburyport East, and Newburyport West quadrangles, has extended the known occurrences and relations of late or postglacial marine clays in northeastern Massachusetts. These clays occur as much as 80 feet above sea level, and are clearly interbedded with ice-contact deposits at a number of localities.

A continuous seismic profile (Sammel, Art. 156) along about 20 miles of the Merrimack River from Plum Island to Haverhill, Mass., shows that the present channel of the river, flowing over unconsolidated sediments, crosses a number of deep places in the underlying bedrock surface. In the 6 miles below Haverhill, the bedrock beneath several reaches may lie more than 200 feet below sea level. In about the lowermost 2 miles, near the ocean, the bedrock is more than 150 feet below sea level at 4 places and more than 200 feet at 1 of the 4. The full geologic implications of these data await further mapping and testing.

Dense aggregates of beaver-felled conifer wood at or near the base of four relatively thick peat bodies in southeastern New England are reported by C. A. Kaye. Two of these bodies are exposed in sea cliffs on Block Island and Martha's Vineyard and two were exposed during the excavation of an underground garage in the Boston Common. Radiocarbon ages of the beaver-felled wood as determined by Meyer Rubin range from about 11,000 to 12,100 years. From the size of the toothmarks it is inferred that the beavers were the present Canadian beaver (*Castor canadensis*). It is possible that these early postglacial beavers dammed fairly well graded stream courses and that much of the swampland of present New England is the direct result of this.

Geologic mapping in Rhode Island

G. E. Moore, Jr., has discovered well-crystallized graphite in muscovite schist from a drill core at Tuckertown and in metaconglomerate from west of Worden Pond in the Kingston guadrangle. The Rhode Island Formation contains much graphite, or meta-anthracite, whereas the Blackstone Series does not, at least in this quadrangle. The rocks at these two localities, therefore, are thought to belong to the Rhode Island Formation and to occur in two separate small basins to the west of the main body of the Rhode Island Formation of the Narragansett Basin.

Several exposures near Westerly, studied by J. P. Schafer, show bedrock that was deeply decomposed in pre-Wisconsin (perhaps pre-Pleistocene) time. This weathered rock was strongly affected by solifluction, probably both before and after the last glaciation of the area.

Geologic mapping in Connecticut

Mapping in the Hampton and adjacent quadrangles by H. R. Dixon has shown that the Pomfret Phyllite and the Woodstock Quartz Schist of Gregory [18] are not valid units but are continuations of the Hebron Gneiss and the Scotland Schist.

The Willimantic dome, an elliptical structure 8 by 16 miles in diameter in eastern Connecticut, has been mapped in detail by G. L. Snyder. The rocks within the dome, previously mapped as the Willimantic Gneiss of Gregory, are now divided into units that are correlated with formations elsewhere in eastern Connecticut. From the center of the dome outward these units are (correlative formation names in parentheses): alaskite (Sterling Granite Gneiss), hornblende gneiss (Monson Gneiss and Middletown Gneiss), a pelitic gneiss (Putnam Gneiss and Brimfield Schist) with a medial calc-silicate and marble member (Fly Pond Member of the Putnam Gneiss), a binary granite (Canterbury Gneiss), and a calc-silicate rock and biotite schist (Hebron Gneiss).

H. R. Dixon has identified a conglomeratic zone in the Putnam Gneiss in the Plainfield quadrangle that appears to mark a transition between overlying aluminous schists and a lower thick series of layered amphibolites and quartz-biotite gneiss. The conglomerate is composed of pebbles and cobbles of various granites, quartzite, schist, and pegmatite in a matrix of sillimanite-pyrite schist. It is highly deformed and, locally at least, the pebbles and cobbles are stretched. The extent of the conglomerate along strike is not yet known, but at this horizon a highly aluminous pyritic schist is

[18] Rice, W. N., and Gregory, H. E., 1906, Manual of the geology of Connecticut: Connecticut Geol. Survey Bull. 6, 273 p.

known to extend southward to the Honey Hill fault and northward into Massachusetts, and may prove to be a good marker unit within the Putnam Gneiss.

C. E. Fritts has revised and refined the stratigraphy of the metasedimentary rocks of pre-Triassic age northwest of New Haven (Art. 128). The Milford Chlorite Schist of Gregory [19] probably underlies the Orange Phyllite of Gregory; previously the Milford was thought to be the youngest formation of pre-Triassic age in the southeastern part of the western highlands of Connecticut. The main part of the Orange Phyllite of former usage, now called the Wepawaug Schist, is believed to occupy a tight syncline plunging gently north-northeast. Tentative correlations have been made with well-established formations in Vermont.

Geophysical studies in New Hampshire

Detailed gravity measurements by M. F. Kane over several New Hampshire ring dikes show extremely sharp anomalies with gradients as high as 40 milligals per mile. Data over the southwest edge of the Merrymeeting stock suggest that a near-surface mafic dike is present along the margin of the intrusive.

Andrew Griscom has made aeromagnetic studies of five intrusions of the White Mountain Plutonic-Volcanic Series. Analysis of the anomalies, which are as large as 4,000 gammas, has provided considerable information concerning the subsurface shape of the intrusions. It was demonstrated from studies of the magnetic properties of samples that two of these intrusions possess a similar anomalous direction of remanent magnetization, down and to the southwest. This direction is very different from that of other rocks of a similar age.

Regional geophysical studies

Gravity profiles across ancient river channels covered by glacial deposits show small but measurable negative anomalies. M. F. Kane suggests that these are caused by the high porosity of the overburden, and that gravity measurements should prove useful in problems concerned with the subsurface configuration of the bedrock.

Results of aeroradioactivity studies by Peter Popenoe in the New England–New York area point up the potential use of airborne radioactivity measurements as an aid to regional geologic mapping in glaciated areas. The studies indicate a local derivation of a large part of the glacial material that mantles the bedrock, so that many bedrock units may be traced by their characteristic level of radioactivity. For instance, the new Hampshire Plutonic Series and the surrounding Ordovician volcanic rocks have a low radioactivity level of 250 to 400 counts per second and may be traced across New Hampshire, Massachusetts, and Connecticut by this level. At two localities departures from the characteristic low level occur: the Croydon Dome of New Hampshire (550–950 cps) and the Glastonbury Gneiss [20] in the vicinity of Meshomasic Mountain in Connecticut (500–1,000 cps).

Ground water in Rhode Island

In an appraisal of the ground-water reservoir areas of Rhode Island, S. M. Lang (1961a) divided the State into 17 areas, most of them consisting of one major ground-water reservoir and the stream-drainage area contributing to it. For each of these areas an appraisal was made of (1) the size of the ground-water reservoir, (2) the amount of natural replenishment, (3) present development of the water in the area, and (4) possible conflict between established water uses and future ground-water developments. Of these 17 areas, 9 are considered to have ground-water reservoirs large enough and potential water use great enough to warrant detailed investigations leading to a quantitative evaluation of the amount of water available. Such investigations are presently underway in three of these areas.

Quality of water in the St. Lawrence River basin

A. L. Mattingly has assembled data on the chemical and physical quality of waters in 12 streams tributary to the St. Lawrence River and the St. Lawrence itself in New York, and from about 30 wells in the drainage area. The dissolved-solids content of the surface water generally ranges from 28 to 94 ppm (parts per million) and the hardness from 12 to 70 ppm. The dissolved-solids content of the ground water ranges from 236 to 1770 ppm and the hardness from 221 to 345 ppm. These variations probably are related to the different types of bedrock that underlie the drainage area.

APPALACHIAN REGION

Results of some of the current geologic, geophysical, and hydrologic studies in the Appalachian region are presented below. Discussion of some topical studies in this area may be found as follows: iron deposits in Alabama, page A1; copper in North Carolina, page A3; pegmatites in North Carolina, page A6; geomorphology in southeastern Pennsylvania, page A76; limestone hydrology, page A107; and radioactive-waste disposal, page A114.

Geologic mapping

Mapping near the Delaware River in New Jersey and Pennsylvania by A. A. Drake, Jr., and J. B. Epstein strongly suggests that the ridges of Precambrian rocks in the Reading Prong may be detached parts of a single thrust sheet. The contact between the Shawangunk

[19] See footnote, p. A18.

[20] See footnote, p. A18.

Conglomerate of Silurian age and the underlying Martinsburg Shale of Middle and Late Ordovician age may be a decollement as well as an unconformity.

Mapping by R. G. Ray in nothern Virginia has shown a series of complex, overturned folds in the Weverton Quartzite foothills on the western side of the Blue Ridge. Recognition in aerial photographs of these folds, extending into the Shenandoah Valley, suggests conformity of the basal clastic rocks with the overlying carbonate rocks, as mapped by Charles Butts, instead of a thrust relation as suggested in earlier reports.

Structural and tectonic studies

J. C. Reed, Jr., and J. L. Jolly have demonstrated that the rocks of the Maryland Piedmont have been affected by at least two periods of regional metamorphism. Rocks of medium- and high-grade regional metamorphism altered by retrogressive metamorphism have previously been mapped as low-grade metamorphic rocks.

In the Grandfather Mountain area of North Carolina, J. C. Reed Jr., and Bruce Bryant have shown that structures of several generations are present in both the autochthonous and allochthonous sequences. Some of the structures formed prior to thrusting and some during thrusting.

Recent mapping by R. L. Miller (Art. 139) has revealed an exposure of the Pine Mountain overthrust fault zone in the "Genessee" black shale near Big Stone Gap, Va., about 20 miles from the nearest previously known exposures.

Stratigraphic studies

Detailed studies in the western part of the Pennsylvania anthracite region by G. H. Wood, Jr., J. P. Trexler, and H. H. Arndt (Art. 74) have demonstrated that the upper member of the Mauch Chunk Formation intertongues with the lowest beds of the Pottsville, and is therefore, at least in part, of Early Pennsylvanian age. The same authors (Art. 72) have subdivided the Catskill Formation in this area into members on the basis of tonguing of marine and continental facies, and have demonstrated that the upper gray member is of Early Mississippian age (also see Art. 73).

Preliminary interpretation of geologic mapping and stratigraphic sections in the Northern anthracite field of Pennsylvania by M. J. Bergin, T. M. Kehn, and J. R. Robertson indicates that the Pocono Formation and the overlying Mauch Chunk Formation intertongue along the northwestern edge of the field, and that the Mauch Chunk Formation thins out abruptly toward the northeast.

Lead-alpha measurements by T. W. Stern on zircon collected by A. A. Stromquist and A. M. White from felsic crystal tuffs in the volcanic-slate belt of the central North Carolina Piedmont have confirmed a previously inferred Ordovician age for these unfossiliferous rocks.

Study of the breccias in the upper part of the Knox Dolomite of eastern Tennessee and southwestern Virginia by Helmuth Wedow, Jr., suggests that much of the matrix consists of the following: (a) graded clastic sediments, including insoluble residues of dissolved limestones, (b) "sanded" dolomite rhombs from the alteration of limestone, and (c) other detritus, including volcanic material, washed down through solution channels from the paleokarst surface at the top of the Knox.

Comparison of well data from central and eastern Kentucky with exposed sections in northeastern Tennessee and southwestern Virginia by L. D. Harris shows that the limestones of the Conasauga Group thin and finger out to the northwest and that the younger Cambrian rocks transgress northwestward across the older, so that the basal sandstone probably ranges in age from Early Cambrian in northeastern Tennessee to Middle Cambrian in central Kentucky.

Petrographic studies of two arenaceous formations of Early Cambrian age in the Philadelphia, Pa., area, by Jane Wallace, have revealed significant differences between them. In the samples examined, the Chickies Quartzite contains not more than 5 percent feldspar in grains up to 1 mm in maximum dimension; but the Antietam Quartzite contains about 50 percent feldspar in grains that average 0.1 mm in size. In addition, the Chickies has a pronounced preferential elongation of grains that is lacking in the Antietam.

Geophysical studies

Five lithologic zones have been identified in the basement rocks of eastern Tennessee as a result of study of aeromagnetic and Bouguer gravity-anomaly maps by J. S. Watkins (Art. 69). Four of these zones strike slightly east of north. A major basement fault which strikes approximately parallel to surface faults of the Valley and Ridge province truncates the zones. Over 400 density determinations by Y. Yuval show that the mean density of the lower Paleozoic limestone and shale sequence of the Valley and Ridge province is between 2.70 and 2.75 g per cc and that the mean density of the Knox Dolomite is between 2.80 and 2.85 g per cc.

Interpretation of aeromagnetic surveys in the Greenwood Lake and Sloatsburg quadrangles, New York and New Jersey, by Anna Jesperson and Andrew Griscom shows that the magnetic pattern duplicates the northeasterly geologic trend, differentiates areas of exposed or near-surface crystalline rocks from areas of sedimentary rocks, and differentiates the three principal units within the crystalline rocks.

Interpretation of gravity and aeromagnetic surveys in the Allentown quadrangle, Pennsylvania, by R. W. Bromery suggests that the Precambrian rocks east of Saucon Valley are denser and more highly magnetic than the apparently similar Precambrian rocks west of the valley.

R. G. Bates (1962b,c) has shown that the average aeroradioactivity levels or patterns of radioactivity units delineate the three major geologic subdivisions in eastern Tennessee and Kentucky. He also shows that within the Valley and Ridge province, the northwest edge of the high radioactivity units (Rome Formation and Conasauga Shale) accurately delineates the traces of the thrust faults that separate these rocks from the younger, less radioactive, largely carbonate rocks.

In the Savannah River area of South Carolina and Georgia, R. G. Schmidt (1961b, 1962) has shown that aeroradioactivity of the granites and some metamorphic rocks is high, that of the adjacent Upper Cretaceous and Eocene rocks is moderate to high, and that of the slate-belt rocks and the post-Eocene formations is generally low. J. A. MacKallor [21] has shown that, in this same area, there is a good correlation between counts per second recorded during flight and percent equivalent uranium (eU) in soil samples collected directly under the flight path of the aircraft; also there is a definite correlation between eU of the soil and the kind of underlying bedrock.

Hydrologic studies

J. W. Stewart (Art. 43) used tests of core samples and pressure tests of core holes in computing the water-yielding potential of metamorphic crystalline rocks in the Piedmont province north-northeast of Atlanta, Ga.

C. L. Dodson has found that sustained yields of water from wells in the Murphy Marble are higher than would generally be expected from wells in the metamorphic rocks of the Murphy area, North Carolina. Only a small part of the area is underlain by marble, but this small part, in addition to having a potentially large ground-water supply for industrial development, is strategically located near railroads and in the widest valleys.

ATLANTIC COASTAL PLAIN REGION

Only findings of regional geologic and hydrologic studies in the Atlantic Coastal Plain are discussed in this section. Additional information on the following topical studies may be found elsewhere in this book: phosphate deposits, page A6; clay deposits, page A7; paleontology, page A74; geomorphology, page A76; plant ecology, page A77; lead-isotope studies, page A96; saltwater encroachment, page A101; coastal erosion, page A106; artificial recharge of aquifers, page A112; and water pollution, page A115.

Regional stratigraphy and structure

H. E. LeGrand (1961) has made a compilation of gross lithologic and major structural features of the Atlantic Coastal Plain. Interpretation of the regional stratigraphy and structure by him indicates that (1) eastward and southeastward-dipping beds lie on a basement of crystalline rocks and, less commonly, on Paleozoic and Triassic sedimentary rocks; (2) the basement is a shallow, nearly flat platform beneath the updip or inner half of the coastal plain, but in southern New Jersey and eastern North Carolina the basement platform steepens eastward and adjoins the west side of a northward-trending trough; (3) the Peninsular arch of Florida and the Cape Fear arch of North Carolina are two northwestward-trending positive elements, with an embayment in southeastern Georgia between them; (4) marine sand and clay predominate in Mesozoic rocks north of Florida and in Cenozoic rocks north of North Carolina; (5) near-surface calcareous rocks of Eocene age extend from Florida through North Carolina; and (6) pre-Pleistocene coastal plain rocks of Florida are largely carbonates.

Stratigraphic studies

Regional subsurface maps of the Upper Cretaceous sedimentary rocks in the coastal plain of Georgia and Florida aid in clarifying some of the episodes in the geologic history of the area. Mapping by Paul and Esther Applin indicate that the sand, shale, and chalky marl of Navarro (Late Cretaceous) age in Georgia, and the lithologically and faunally distinct Lawson Limestone (Late Cretaceous) in the Florida peninsula represent contemporaneous deposition in closely associated areas of dissimilar environment. The Applins interpret their data as indicating that the two types of sediments were separated by an upwarped barrier in the older beds of Taylor and Austin age. The barrier, which extended west-southwestward across southern Georgia and western Florida during the latter part of the Late Cretaceous, was apparently downwarped in Tertiary time. Contemporizing these units will have a significant effect on future Atlantic coast stratigraphy.

Preliminary sampling and analysis of the "Tuscaloosa," Black Creek, and Peedee Formations along the Cape Fear, Neuse, and Tar Rivers, N.C., by Linn Hoover and others indicate that marked differences occur in the sedimentary components, but the persistency

[21] MacKallor, J. A., 1962, Aeroradioactivity (ARMS–1) and general geology of the Georgia Nuclear Laboratory area, northern Georgia: U.S. Atomic Energy Comm. Report CEX– 58.4.8.

and the degree and direction of change in each unit has not been established.

Surface and shallow subsurface mapping of Quaternary deposits in seven 7½-minute quadrangles in New Jersey by J. P. Owens and J. P. Minard has shown that the classical division of the Quaternary into three stages during which terrace deposits were laid down is not applicable to the area. Most of the Quaternary deposits are recognized by internal structures such as stream-channel and overbank deposits, and they show close lithologic correlation with source rocks nearby. The location of the deposits is related not to a sequence of terraces of decreasing altitude but to the gradients of individual streams.

S. M. Herrick (Art. 21) has identified a middle Eocene fauna, characterized by *Marginulina vacavillensis* (Hanna), in a test well drilled in Camden County, N.J. The fauna occurred in the Manasquan Formation, which is considered by Herrick to bear strong lithologic and faunal similarity to the Weches Greensand Member of the Mounty Selman Formation of Texas and the Cook Mountain Formation of Louisiana.

D. R. Rima, correlating by means of gamma-ray logs, has traced the marine Upper Cretaceous formations of New Jersey southwestward along the strike through Delaware. Rima's work substantiates previous stratigraphic interpretations in the area based on lithologic and faunal studies.

Examination of deep-well cores from Florida by J. M. Schopf revealed microscopic *Chitinozoa* similar to forms from Oklahoma in the Sylvan Shale of Late Ordovician (Richmond) age. These problematic acid-resistant microfossils are being compared also with assemblages from the Upper Ordovician in Ohio and Kentucky.

Hydrologic studies

E. R. Lubke (1961a) has prepared a contour map of the buried Cretaceous surface in the Huntington-Smithtown area of Suffolk County, Long Island, N.Y., that depicts 5 major buried valleys, one of which is cut 450 feet below sea level. These valleys are potential conduits for the movement of salt water from Long Island Sound into Cretaceous aquifers. John Isbister has recognized the presence of similar valleys in northeastern Nassau County, Long Island.

P. R. Seaber has divided the sequence of coastal plain sediments in New Jersey into eight major geohydrologic units that comprise arealy extensive artesian-aquifer systems, aquiclude systems, and a water-table aquifer system. At least two aquifer systems are available for development in any section of the coast plain.

According to H. B. Counts and M. J. McCollum, current-meter tests in deep wells in the principal artesian aquifer in the vicinity of Savannah, Ga., have defined 4 permeable zones (totaling 100 to 150 feet in thickness) within a 600- to 700-foot-thick section of limestone. The relative permeability of each zone, the approximate contribution of water to the well from each zone, and the approximate water velocity in each zone have been determined as an aid to studies of salt-water encroachment in the Savannah-Brunswick area, Georgia.

Origin of the Carolina Bays

A survey of the literature on segmented lagoons and elliptical lakes by E. C. Robertson indicates that the segmented-lagoon hypothesis advanced in 1934 by C. Wythe Cooke to explain the Carolina Bays of the Atlantic Coastal Plain deserves renewed consideration. Robertson (Art. 92) reviews recent studies of elliptical lakes, including some lakes in the Chukotsky Peninsula of Siberia, and describes the segmentation of lagoons by the growth of cuspate spits. The prevailing wind direction is perpendicular to the elliptical lagoon segments. The new hypothesis explains some features of the bays not explained in the original lagoon hypothesis of Cooke and, if correct, means that the bays must have formed as the sea retreated from the Atlantic Coastal Plain.

EASTERN PLATEAU REGION

Recent geologic, hydrologic, and geophysical work of regional significance is summarized below. Much of this work is carried on in cooperation with various State agencies. Additional summary statements on topical subjects may be found as follows: mineral deposits, pages A2 and A7; water resources, Utica-Rome area, New York, page A12; plant ecology, page A77; limestone hydrology, page A103; and water pollution, page A115.

Geologic and geophysical studies in Kentucky

During mapping of coal-bearing strata in the vicinity of Jackson in eastern Kentucky, W. R. Hansen and others (Art. 76) have defined the Frozen Sandstone as a new member of the Middle Pennsylvania Breathitt Formation. The Frozen Sandstone Member is about 40 feet thick, and its base is about 80 to 100 feet above the base of the Breathitt Formation. Because it is both widely exposed and easily recognized in an area of generally poor outcrops, the Frozen Sandstone Member is an excellent stratigraphic marker within the thick Breathitt Formation.

Detailed mapping and stratigraphic studies of the Lower Pennsylvanian Lee Formation in the Middlesboro area of southeastern Kentucky by K. J. Englund show a previously unrecognized unconformity in the upper part of the formation. The erosional surface, which truncates about 300 feet of underlying strata, is accompanied by a reversal in depositional trend above the unconformity. Sandstone tongues of the Lee below the unconformity wedge out toward the northwest; those above the unconformity wedge out to the east or southeast. This is interpreted as indicating a change from an eastern or southeastern source to a northwestern source, the latter source originating from uplift and cannibalism of previously deposited Lee sediments in the general region of the Cincinnati arch. The possibility that this unconformity is regional is significant in that it may be related to the Mississippian-Pennsylvanian boundary of the midcontinent region.

Work by R. A. Sheppard and Ernest Dobrovolny near Carter Cave State Park, northeastern Kentucky, has demonstrated that a sandstone lithologically similar to sandstones of the Lee Formation of Early Pennsylvanian age occurs in the underlying Pennington Formation of Late Mississippian age. The sandstone lies upon limestone older than the Pennington and is overlain by more than 10 feet of fossiliferous shale and thin-bedded limestone typical of the Pennington Formation. Stratigraphic and paleontologic evidence suggests that sands which are similar to, if not part of, the Lee Formation were accumulating during Late Mississippian time. This accords with the intertonguing of the Pennington and Lee Formations in southeastern Kentucky as described by Englund and Smith.[22]

J. S. Watkins has recently completed a Bouguer gravity map of Kentucky which was begun by R. W. Johnson, Jr. Study of the gravity map indicates that the basement beneath the Jessamine dome (northern part of the Cincinnati arch) is composed of low-density sialic rock, and that the persistent high structural position of the dome may be due to partial isostatic compensation of the low-density mass. The addition of new data to that already available in eastern Kentucky shows that several small anomalies are elongate parallel to the Appalachian structures. Previous data had tended to suggest that there was little or no relationship between the basement and surface Appalachian structures in Kentucky. Of the numerous faults in Kentucky, only those in the central part of the Rough Creek fault zone appear to be associated with significant basement faults.

Geologic studies in Pennsylvania

Current geologic mapping and stratigraphic studies in Washington County, Pa., by H. L. Berryhill, Jr., and V. E. Swanson (Art. 75) have yielded data that permit a revised nomenclature and classification for the Pennsylvanian and Permian rocks. Mapping has demonstrated that coal beds are the most distinctive and most easily correlated units; further, the many intervening sandstone and limestone units are so similar that they can be correlated only when related to an underlying or overlying coal bed. Therefore, the basic mapping unit for field classification includes the several rock types between coal beds, and the basic units represent a sedimentary cycle. These units have been designated as members and, where possible, the member has been assigned the name of the coal bed at its base. In Washington County, the formation boundaries have been placed at the bases of the most important and persistent thick coal beds, and the name assigned to the formation is that of the major coal bed at its base. Each formation includes two or more members that represent sets of similar and related sedimentary cycles. In ascending order, the stratigraphic units defined are: the Monongahela Group, which includes the Pittsburgh (5 members) and Uniontown (2 members) Formations of Pennsylvanian age; the Dunkard Group, which includes the Waynesburg Formation (3 members) of Pennsylvanian and Permian age; and the Washington (3 members) and Greene Formations of Permian age.

Preliminary data collected by G. W. Colton in the Cedar Run quadrangle, Lycoming and Tioga Counties, Pa., suggest that the Upper Devonian Catskill Formation can be divided into several mappable units which possibly will be designated as formations at a later date. Recognition of these units has aided in delineating the structure of the area and should aid in interpreting the stratigraphy of Upper Devonian rocks in north-central Pennsylvania and contiguous areas.

Geologic studies in New York

Subsurface stratigraphic studies by Wallace de Witt, Jr., show that the Genesee, Sonyea, West Falls, Java, and Perrysburg Formations of Late Devonian age can be recognized in the subsurface of southwestern New York. Several members, which are composed largely of black shale, have been traced widely in Schuyler, Steuben, and parts of adjacent counties.

Paleontologic studies of compound rugose corals of the Onondaga Limestone by W. A. Oliver, Jr., support a Middle Devonian age for the formation. The colonial corals are most abundant in the reef facies, common in biostrome facies, but rare in other parts of the Onondaga.

Geologic studies in Alabama

A geomorphologic study by J. T. Hack of the Russell Cave National Monument, Ala., in the limestone region near the southern end of the Cumberland Plateau distinguishes the geologic featues that apparently controlled the location of the cave, as well as other

[22] Englund, K. J., and Smith, H. L., 1960, Intertonguing and lateral gradation between the Pennington and Lee Formations in the tri-State area of Kentucky, Tennessee, and Virginia: Geol. Soc. America Bull., v. 71, p. 2015.

caves of the region. The valley walls in the area are about 1,000 feet high. The lower 750 feet is mostly limestone of Mississippian age and the upper 250 feet is shale, coal, and massive sandstone of the Pottsville Formation of Pennsylvania age. The sandstone that caps the plateau is the source of numerous aprons of talus and inactive slides that extend to the valley floor. The floors of the limestone valleys are completely blanketed by cobbles of the sandstone. Because of the large quantity of sandstone debris shed onto the valley floor, the stream channels tend to migrate toward the sides of the valley where they are captured by sinks and carried off downdip in the limestone. Numerous undrained depressions in the gravelly floor of the valley indicate that much of the erosion is by solution, and the gravel is removed only during floods that do not run off underground.

Surface-water studies in Kentucky

C. R. Collier and J. J. Musser found that weathering and subsequent erosion of the spoil banks formed by strip mining for coal in the Cane Branch basin, McCreary County, Ky., has greatly increased the sediment load of Cane Branch. The sediment yield of the Cane Branch basin (6 percent strip mined) at the measuring station was 1,900 tons per square mile of drainage area in the 1958 water year. In contrast, the nearby Helton Branch basin had no strip mining and yielded less than 30 tons per square mile of drainage area.

Quaternary geology of the lower Ohio River valley

A completed study by L. L. Ray has demonstrated that each zone of the profile of weathering developed on thick well-drained sections of Peorian Loess adjacent to the Ohio Valley between Louisville, Ky., and Cairo, Ill., is characterized by a distinctive silt-clay ratio. Continuing studies indicate that with increasing distance from the valley, deposits become thinner and commonly less well drained, and that there is a progressive change in the silt-clay ratio from one zone to another within the weathering profile.

Quality of ground water, Delaware County, New York

Ground water containing moderate to large amounts of hydrogen sulfide, chloride, and natural gas is reported by J. Soren in wells tapping Upper Devonian continental rocks in Delaware County, N.Y. Excessively hard water has also been pumped from wells in these rocks. In most instances the wells yielding objectionable constituents are located near crests of eroded low anticlines. The constituents are believed to migrate with ground water through faults and joints from underlying marine Middle and Lower Devonian rocks.

SHIELD AREA AND UPPER MISSISSIPPI VALLEY REGION

Results of recent geologic, geophysical, and hydrologic studies in the Shield area and in the upper Mississippi Valley region are described in the following paragraphs. Much of this work was done in cooperation with State agencies. Additional information on mineral deposits is presented on page A1, aeromagnetic prospecting on page A5, glacial geology on page A78, rubidiumstrontium age determinations on page A94, limnological studies on page A103, airborne radioactivity surveying on page A115, and isotope geology on page A122.

Geologic and geophysical studies

Some of the conglomerate at the base of the Wewe Slate south of Goose Lake in the eastern part of the Marquette district, Michigan, has been found to consist of rounded and angular granitic cobbles and pebbles in a matrix of thinly laminated slate. J. E. Gair believes that the cobbles and pebbles were ice-rafted into the area and were deposited in accumulating thinly layered, possibly varved, muds.

The Quinnesec Formation in southern Florence County Wis., was described by Van Hise and Leith[23] as overlying and interbedded with sedimentary rocks of middle Precambrian age (upper Huronian of that report), but stratigraphic equivalents in Wisconsin and Michigan have recently been tentatively considered to be of early Precambrian age. Investigation of critical areas in Florence County by C. E. Dutton revealed that pillows in metabasalt of the Quinnesec Formation show that the top of the unit is northward toward middle Precambrian quartzite in which crossbedding indicates that its top is southward. A major fault with relative uplift of the south side is inferred to pass between these two stratigraphic units, and the early Precambrian age of the Quinnesec Formation remains likely. A metarhyolite that lies between the metabasalt and the inferred fault appears to be a younger part of the Quinnesec Formation. Interbedded volcanic and sedimentary rocks present north of the fault are apparently part of the Michigamme slate of middle Precambrian age.

J. R. Henderson reports that aeromagnetic-contour maps will be prepared and interpreted geologically for a 15,000-square-mile area of that part of the "midcontinent gravity anomaly" that crosses Iowa. This spectacular gravity feature extends for about 800 miles southwestward from Lake Superior to the Salina Basin

[23] Van Hise, C. R. and Leith, C. K., 1911, The geology of the Lake Superior region: U.S. Geol. Survey Mon. 52, 641 p., 49 pl.

of Kansas. Mathematical analysis of the aeromagnetic data will permit estimates of total thickness of the Paleozoic and Mesozoic sedimentary section and provide a basis for speculation about the character, configuration, and distribution of basement rocks.

Radioactivity levels in part of Ohio and Indiana ranged from 300 to 1,000 cps (counts per second) and averaged 450 to 500 cps, according to R. G. Bates. The cause of a 700- to 1,000-cps high reading a few miles northwest of Columbus, Ohio, is not known, but the high values may be due to fertilizers used on the fields of the Ohio State Experimental Farm. No correlation of radioactivity levels and bedrock geologic units has yet been noted because of the masking effect of glacial deposits that cover all but the southeast corner of the survey area. Neither has any correlation between radioactivity levels and morainal and outwash deposits been noted, probably owing to the loess cover that mantles much of the area, Preliminary study indicates that the radioactivity level over belts of boulders transported from Canada by the Wisconsin ice is slightly higher than over the surrounding glacial deposits. Radioactivity levels over urban areas were generally 50 cps lower than over the surrounding countryside.

A survey of part of Illinois and Indiana shows that the level of aeroradioactivity of the Chicago area is low to moderate, and G. M. Flint, Jr., reports that specific correlations with geology are precluded by general homogeneity of the Pleistocene surficial material. In general, however, dune-sand deposits and old lakebeds have low radioactivity, whereas morainal materials probably derived in part from the Paleozoic sedimentary rocks that constitute the floor of Lake Michigan have comparatively moderate radioactivity.

An aerial radiological-measurement survey of Minnesota and Wisconsin covered 10,000 square miles centered at the nuclear reactor of the Rural Cooperative Power Association at Elk River, Minn., and included metropolitan Minneapolis–St. Paul. According to J. A. Pitkin the area surveyed is characterized by low to moderate levels of background radioactivity. A distinctive radioactivity low north of Minneapolis-St. Paul is associated with the Anoka sand plain. This plain is composed dominantly of poorly stratified fine-grained quartzose sand with lenses of gravel and is the result of the eastward diversion of the Mississippi River by a late Pleistocene ice sheet.

Hydrologic studies

L. W. Howells estimates that 2,200,000 acre-feet of water is stored in the 2 glacial-outwash aquifers in western and northern Sanborn County, S. Dak. More than 20,000 acre-feet of water could be withdrawn annually without exceeding average recharge. The western aquifer contains water under both water-table and artesian conditions and is recharged within the county, but the eastern aquifer contains water under artesian conditions only and does not receive recharge within the county.

Well logs and water analyses indicate that the Dakota Sandstone in Sanborn County, S. Dak., may be divided into three water-bearing zones. The shallowest and the deepest zones contain dissimilar chemical types of water and the middle zone contains water of intermediate chemical character. The zonation may be modified or destroyed over or near highs in the Precambrian surface and locally where corroded well casings may permit leakage of water between zones.

In an investigation of the Skunk Creek–Lake Madison drainage basin the amount of water available from the glacial outwash was estimated by M. J. Ellis and D. Adolphson to be about 154,000 acre-feet annually. Natural discharge from the basin is by surface flow and underflow into the Big Sioux River and into the outwash deposits along its valley near the city of Sioux Falls, S. Dak.

Studies in Ohio by G. D. Dove have established that fairly large amounts of ground water are available from outwash sand and gravel in the valley of the Hocking River in Fairfield County. The river is a potential source of recharge to the aquifer. The largest user of water in the valley is the city of Lancaster, which pumps about 2½ mgd from 6 wells.

An interesting method of determining the flow system from the Miami River at Dayton, Ohio, to a well field tapping the valley-train deposits was developed by S. E. Norris and A. M. Spieker (Art. 42). The technique consists of precise measurements of the temperature-depth relation in wells. Changes in temperature indicate the depth of relatively impermeable till layers and their effect on the movement of ground water.

Reconnaissance investigations of ground-water resources in Minnesota recently have revealed previously unknown sources of ground water from glacial deposits. Studies by G. R. Schiner and others in the northern part of the Lake Agassiz basin in Minnesota have shown that large quantities of good-quality ground water are available from glacial-outwash aquifers underlying a Lake Agassiz beach ridge. The economic development of the region has been hindered by scarce water supplies and poor-quality water. Further studies suggest that additional outwash aquifers, capable of producing at least moderate supplies of water, underlie or are in line with other beach ridges in the area.

Robert Maclay reports that large amounts of ground water are available in a narrow channel of buried outwash at Aurora, Minn. The channel, which contains 2 outwash bodies about 30 feet in thickness, extends southward from the Mesabi Range in St. Louis County to the St. Louis River.

GULF COASTAL PLAIN AND MISSISSIPPI EMBAYMENT REGION

The geologic, geophysical, and hydrologic studies in the Gulf Coastal Plain and Mississippi Embayment region discussed below illustrate the diversity of activity of Geological Survey personnel in this large area. In addition to these studies of a more regional nature, the following topical subjects are summarized on the pages indicated: floods, page A99; low flows, page A100; stratigraphic paleontology, page A75; hydrochemical facies, page A90; and underground nuclear testing in Mississippi, page A109.

Aerial radiological studies, southeast Texas

R. M. Moxham and D. H. Eargle (1961) in making a comparison of airborne radioactivity studies with mapped geologic units in southeast Texas show that many stratigraphic units can be distinguished on the basis of radioactivity intensities, but not where the units are covered by more than a few feet of residual soils or surficial deposits. This finding suggests the possibility that airborne radioactivity studies may prove valuable in preparing regional and reconaissance maps in areas where conditions are similar to those in southeast Texas.

Subsurface geology, Little Rock, Arkansas, to Cairo, Illinois

Aeromagnetic mapping in the vicinity of Little Rock, Ark., and northward to Cairo, Ill., indicates a near-surface nepheline syenite mass a few miles southeast of Little Rock, in an area that may contain an accumulation of bauxite. Magnetic anomalies between Little Rock and Cairo are interpreted as expressions of the Precambrian crystalline basement, a mile or two beneath the surface. Lower and Middle Cambrian sedimentary rocks are believed to be very thin or absent within the area of study.

Faulting in western Kentucky

Geologic investigations in the Jackson Purchase area of western Kentucky by U.S. Geological Survey personnel have revealed that several faults with throws of as much as 150 feet have displaced beds ranging in age from Ordovician to Recent. One fault with about 30 feet of displacement reportedly formed during the New Madrid earthquake of 1811–12. Most of the faults trend west-southwest and northwest and are continuations of known faults that displace Paleozoic rocks in adjacent areas north and east of the Tennessee River.

Southeastern Gulf Coastal Plain studies

L. D. Toulmin and P. E. LaMoreaux have described and differentiated rocks of Tertiary age cropping out along the Chattahoochee River. Exposures of these rocks, which provide the only continuous unweathered geologic section in southwestern Georgia and southeastern Alabama, soon will be largely covered by backwaters of dams now under construction. The section serves as a connecting link between geologic units to the east and west that have been differentiated in outcrop. The determination of rock types will aid in locating the formations in the subsurface of adjacent areas where some are sources of large quantities of ground water.

R. H. Musgrove and others have studied the water resources of Escambia and Santa Rosa Counties in northwestern Florida. This expanding industrial area has many streams with high base flows and two productive aquifers. Development of ground water is principally from a sand-and-gravel aquifer several hundred feet thick which overlies the Floridan aquifer. Saltwater encroachment is being detected in coastal estuaries and some stream channels.

Mississippi Embayment hydrologic and geologic studies

E. M. Cushing and E. H. Boswell report that, according to electric logs of wells and oil tests, all sands above the Paleozoic rocks probably contain fresh water in northeastern Arkansas, Missouri, Illinois, Kentucky, Tennessee, northeastern Mississippi, and northwestern Alabama. These sands are of Late Cretaceous age and younger. Sands of Late Cretaceous age are used as a source of water supply in only about one half of this area of approximately 30,000 square miles. The study also indicates that sands of Early Cretaceous age in a small area in east-central Mississippi may be a potential source of fresh water. In several small areas within the embayment, fresh-water-bearing sands occur below sands containing moderately mineralized water.

A study of Upper Cretaceous gastropods of northeastern Mississippi by N. F. Sohl affords a sound basis for correlating the lower part of the Coffee Sand with the middle part of the Blufftown Formation of Georgia and Alabama, and with the Wolfe City Sand Member of the Taylor Marl in Texas. *Scaphites hipprocrysis*-like ammonites in the middle part of the Blufftown suggest correlation with the New Jersey Merchantville Formation.

S. M. Herrick has identified *Robulus inornatus* (d'Orbigny) in the Cane River Formation of eastern Arkansas. Owing to its association with *Marginulina vacavillensis* (Hanna) elsewhere in the Mississippi Embayment this discovery permits a part of the Cane River Formation of Arkansas to be correlated with the Winona Formation in Mississippi.

After correlating the results of chemical analyses of low-flow water samples from the Mississippi Embayment area of Alabama and Mississippi, W. J. Welborne reports that streams (at low flow) originating in outcrop areas of the Eutaw Formation and Tuscaloosa Group of Cretaceous age in northeast Mississippi and northwest Alabama contain water of extremely low mineral content. In general, stream mineralization increases south and west toward the Mississippi River as the result of water draining from younger, less leached formations.

Hydrologic studies in Arkansas and Texas

Geohydrologic studies made by D. R. Albin show that the Porters Creek Clay of the Midway Group is the fresh-water "basement" of the 2,000 square mile area of Bradley, Calhoun, and Ouachita Counties in south-central Arkansas. At least small supplies of ground water can be developed in the outcrop areas of all geologic units above the Porters Creek Clay. The Sparta Sand of the Claiborne Group, the most important aquifer in the area, dips eastward approximately 30 feet per mile toward the axis of the Mississippi trough. About 5 mgd of sodium-bicarbonate type water is withdrawn from the Sparta Sand in the 3 counties. The Sparta in the eastern part of the three-county area is capable of supporting much larger pumpage.

L. A. Wood has mapped a previously unknown body of fresh to slightly saline ground water in the Trinity Group in the lower Red River and Sulphur River basins of Texas. In much of this area no usable water overlies the newly discovered aquifer, which is 2,000 to 3,600 feet below the land surface.

The effect of salt springs and seeps on the quality of water in the Brazos River is described by B. Irelan and H. B. Mendieta (Art. 54). They report that the average load of chloride during base flow from the Salt Croton Creek basin was computed to be 400 tons per day. (Also see p. A29.)

OZARK REGION AND EASTERN PLAINS REGION

Current work in the Ozark region and Eastern Plains region includes geologic, geophysical, and hydrologic studies of both regional and local interest. Some of the important recent results of this work are discussed below. In addition, specific references to other studies in this area may be found on the following pages: potash deposits, page A6; paleontology, page A74; geomorphology, page A76; limestone hydrology, page A103; underground nuclear testing, page A108; ground water in Oklahoma, page A111; evaporation suppression, page A112; and artificial recharge of aquifers, page A112.

Geologic studies in southeast Missouri

In the Lesterville quadrangle of southeast Missouri, T. H. Kiilsgaard has mapped the Black fault a distance of 8.5 miles southeastward beyond the point where the fault previously was believed to terminate. Dolomitic rocks of Late Cambrian age have been displaced along this steeply dipping normal fault; those on the southwest side have been dropped at least 260 feet.

Kiilsgaard also found that near Lesterville a white coarse-textured vuggy to cavernous dolomite facies transgresses the Bonneterre, Davis, and Derby and Doe Run Formations, and extends into the lower part of the Potosi Dolomite where the different formations lap onto hills of Precambrian igneous rocks. It remains to be determined whether the facies is of organic origin, such as a series of reefs that originally were anchored to the Precambrian hills, grew through successive periods of sedimentation, and then subsequently were dolomitized, or whether the facies originated from dolomitization in an environment influenced by Precambrian topography.

Stratigraphic studies in Arkansas

Mapping in the Snowball quadrangle in north-central Arkansas by S. E. Frezon has shown that there are three sets of fluvial valley-fill deposits of Pleistocene(?) age along the Buffalo River. The deposits indicate that several cycles of deposition and erosion occurred along the larger streams in the Ozark region in Pleistocene(?) time. These deposits are similar to and may be related to cyclic deposits of Pleistocene age in the Mississippi River valley.

Aeromagnetic survey in the Wichita Mountains

Andrew Griscom and Anna Jespersen have found that magnetic anomalies in the Wichita Mountains system of Oklahoma and Texas result from the Precambrian basement rocks. Some of the anomalies indicate the presence of significant remanent magnetization. The aeromagnetic patterns show that in general the Precambrian rocks, which are in uplifted fault blocks, extend outward from their areas of outcrop at relatively shallow depth for distances of a mile or two. Steep magnetic gradients mark the position of the faults at the margins of these blocks. The complexity of the fault pattern and the variety in depth of burial of the blocks of Precambrian rocks indicate a highly fractured basement.

Aerial radiological measurements in New Mexico

J. A. MacKallor has found that aerial radiological measurements over a playa, Red Lake, in Eddy County, N. Mex., show radioactivity of 500 to 600 counts per second in contrast to 300 to 400 counts per second over the surrounding area. He suggests that the anomaly may result from small amounts of potassium salts that may have been concentrated in the playa deposits.

Geologic mapping in Texas

Geologic mapping by Eargle,[24] Stafford, [25] [26] Terriere,[27] and D. A. Myers has shown that the Cisco Group (Pennsylvanian) and the lower part of the Wichita Group (Permian) contain many discontinuous channel-fill deposits of sandstone and conglomerate, all of which mark local disconformities. There is no evidence to indicate a widespread unconformity at the boundary between the Pennsylvanian and Permian Systems in the area between the Colorado River and the Clear Fork of the Brazos River in north-central Texas.

Geologic mapping by D. A. Myers in the Wayland quadrangle, Stephens and Eastland Counties, Tex., has shown an increase in amount of channel-fill sandstone and conglomerate in the Cisco Group from south to north. This is in keeping with data presented by Eargle [24] for the Colorado River drainage basin on the south, and with that presented by Lee and others [28] for and area to the north of the Wayland quadrangle where a large part of the Cisco Group is a chaotic sequence of channel-fill deposits.

Geologic mapping by V. L. Freeman in the Shumla quadrangle, Texas, has revealed more details about the effects of the Terrell arch on the thickness and distribution of sedimentary strata. Near Comstock the Georgetown Limestone is overlain by the Del Rio Clay, of former usage but northward the Del Rio pinches out against the arch, and the overlying Buda Limestone rests on the Georgetown. The problematical "yellowish marl" of northern Val Verde County was found to be a weathered phase of the middle unit of the Buda Limestone, as has been recognized by several geologists working in the area. It is separated from the Georgetown Limestone locally by less than 1 foot of the lower part of the Buda.

Ground-water recharge, Arkansas River valley, Arkansas

A recent study by M. S. Bedinger, L. F. Emmett, and H. G. Jeffery of ground-water conditions in the alluvium along the 200-mile segment of the Arkansas River between Fort Smith and Little Rock, Ark., has shown that the present pumpage of 3.2 mgd from the aquifer in the alluvial deposits represents less than 3 percent of the quantity of ground water available from natural recharge. The aquifer is recharged by direct penetration of rainfall at an estimated rate of 10 inches per year.

Extensive test augering has shown the aquifer to be continuous and in hydraulic connection with the river. Thus the quantity of water potentially available by inducing recharge from the river is many times that available from natural recharge along the river.

Water-table decline, Grant and Stanton Counties, Kansas

Ground water pumped for irrigation in Grant and Stanton Counties, Kans., is obtained primarily from storage, according to S. W. Fader, E. D. Gutentag, D. H. Lobmeyer, and W. R. Meyer. About 248,000 acre-feet of water is pumped annually for irrigation from unconsolidated deposits of Pliocene and Pleistocene age. From 1940 to 1960 the water table declined about 40 feet in part of the area, and the decline averaged 8.2 feet for both counties. The two counties are underlain by about 55 million acre-feet of ground water in storage.

Fresh water at great depth in Oklahoma

D. L. Hart, Jr., reports that a zone of fresh water extends to depths greater than 3,000 feet in the Limestones of the Arbuckle Group, in the Arbuckle Plateau region of Johnson, Pontotoc, and Murray Counties, Okla. Although the lateral limits have not yet been delineated, the zone probably underlies about seven townships. Fresh water in adjacent areas generally is available to depths of only 600 feet or less. The large contrast in depths at which fresh water occurs is probably a result of the large recharge area and the relatively high permeability of the limestone, which allows fresh water to circulate to great depths and to flush and dilute the mineralized water in the aquifer.

Ground-water recharge, High Plains, New Mexico

During 1960 two periods of excess rainfall and cessation of pumpage due to extensive hail damage to crops caused significant rises in ground-water levels throughout the High Plains of Lea County, N. Mex. Preliminary estimates by J. S. Havens show a net gain of about 483,000 acre-feet of resaturated sediments. If a specific yield of 20 percent is assumed, this represents about 100,000 acre-feet of apparent recharge to the aquifer, the Ogallala Formation of Tertiary age. Estimated total withdrawal of water from the aquifer was 124,000 acre-feet for the same period. If it is assumed that this amount must be added to the aquifer before any rises in the water table are shown, recharge to the Ogallala Formation in Lea County totaled 220,000 acre-feet for 1960.

[24] Eargle, D. H., 1960, Stratigraphy of Pennsylvanian and lower Permian rocks of Brown and Coleman Counties, Texas: U.S. Geol. Survey Prof. Paper 315–D, p. 55–78.

[25] Stafford, P. T., 1960, Geology of the Cross Plains quadrangle, Brown, Callahan, Coleman, and Eastland Counties, Texas: U.S. Geol. Survey Bull. 1096–B, p. 39–72, pls. 4–5, figs. 7–14. [1961]

[26] Stafford, P. T., 1960, Stratigraphy of the Wichita Group in part of the Brazos River valley, North Texas: U.S. Geol. Survey Bull. 1081–G, p. 261–280. [1961]

[27] Terriere, R. T., 1960, Geology of the Grosvenor quadrangle, Brown and Coleman Counties, Texas: U.S. Geol. Survey Bull. 1096–A, p. 1–35.

[28] Lee, Wallace, and others, 1938, Stratigraphic and paleontologic studies of the Pennsylvanian and Permian rocks in north-central Texas: Texas Univ. Bull. 3801, 252 p.

Ground water in the Entrada Sandstone

F. D. Trauger and F. X. Bushman report that ground water occurs under water-table conditions in the alluvium but generally is under artesian conditions in the Entrada Sandstone of Jurassic age, which is the principal aquifer for the city of Tucumcari, N. Mex., and the area southwest and west of the city. The Entrada Sandstone in the structural basins west of Tucumcari and the older alluvium underlying the city together contain available ground water of good quality sufficient to supply the city and rural domestic and stock needs for several hundred years at the current rate of use.

The coefficient of transmissibility of the Entrada Sandstone is about 1,500 gallons per day per foot. Pumping tests show that drawdown of water levels in the Entrada Sandstone tends to be excessive, and interference between closely spaced wells is comparatively great.

The rate of movement of water through the Entrada Sandstone is slow because of the relatively low permeability of the formation. Calculations for 2 general areas in the structural basin show the rate of movement to be about 15 feet per year for both areas. It would require about 1,700 years at the rate of 15 feet per year for water to move from the areas of recharge on the periphery of the structural basin to the city well fields.

Post-Rustler red beds correlated

The age and correlation of the post-Rustler red beds of southeast New Mexico have been in question since 1935. J. B. Cooper (Art. 9) suggests that these red beds are most closely associated with rocks of Permian age and are correlative with the Dewey Lake Redbeds. "Pierce Canyon Redbeds," the name given to this unit in the past, has been abandoned in favor of Dewey Lake Redbeds.

Sources of salinity in the upper Brazos River basin, Texas

An investigation of the salt load in the Brazos River in Texas by R. C. Baker, L. S. Hughes, and I. D. Yost, shows that more than 50 percent of the chloride load at Possum Kingdom Reservoir originates in the Salt Croton and Croton Creek basins. The source of the salt is the Permian rocks from which the salt springs and seeps discharge. The source of the water discharging in the Croton Creek basin is precipitation in the Duck Creek basin. The collection and disposal, either by evaporation or by subsurface disposal, of the total flow of Salt Croton Creek would reduce the chloride load of the Brazos River by about 45 percent; disposal of the baseflow of Salt Croton Creek would result in a reduction of about 30 percent. (Also see Art. 54.)

NORTHERN ROCKIES AND PLAINS REGION

Current investigations of the Geological Survey are extremely varied in this area that includes large parts of North Dakota, South Dakota, Montana, Idaho, and Wyoming, and small parts of Washington, Utah, Colorado, and Nebraska. Some recent findings of regional studies are presented in this section and additional information on topical studies may be found as follows: mineral deposits are described in the sections starting on pages A1, A5, and A10; oil shale, page A11; paleontology, page A74; plant ecology, page A77; Pierre Shale studies, page A89; geochemistry of hot springs, page A89; and geochemistry of surface water, page A90.

Geologic and geophysical studies in northeastern Washington and northern Idaho

In northern Stevens County, Wash., R. G. Yates has found swarms of lamprophyre and related felsic dikes, which intruded Tertiary albite granite late in the igneous and tectonic cycle. Chemical analysis of the dike rocks indicates that they are part of a pronounced differentiation sequence of alkaline character, and thin-section study shows abundant carbonate, probably of primary origin, and disequilibrium relations among the mafic minerals.

In the Hunters quadrangle, Washington, A. B. Campbell has mapped a stratigraphic unit composed of graptolite-bearing thin-bedded dark-gray impure limestone and black slate. According to R. J. Ross, Jr., the graptolites are from the *Climacograptus bicornis* zone, Early Caradoc stage of the Middle Ordovician. The unit is thus equivalent, at least in part, to the Ledbetter Slate of the Metaline mining district, and its occurrence in the Hunters quadrangle extends considerably the known distribution of Ordovician rocks in northeastern Washington.

In the Wilmont Creek quadrangle, Washington, adjacent to the Hunters quadrangle on the west, G. E. Becraft has shown that metamorphic rocks in the north-central part of the quadrangle originally included in the Covada Group by J. T. Pardee[29] are distinctly different from rocks farther north and east that Pardee also included in the Covada Group. The rocks mapped by Becraft apparently were originally shale, sandy shale, and calcareous shale, and do not contain the large amount of greenstone and conglomeratic graywacke present in the Covada Group farther east.

A reconnaissance gravity survey by W. T. Kinoshita and W. E. Davis in Ferry and Stevens Counties, northeastern Washington, has shown that the boundary be-

[29] Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation, Washington: U.S. Geol. Survey Bull. 677, 186 p., 12 pls.

tween miogeosynclinal rocks of early Paleozoic age and eugeosynclinal rocks of late Paleozoic and Mesozoic age is marked by a broad northeast-trending gravity high, and that the Tertiary volcanic rocks exposed near Wauconda and in the Republic graben are marked by gravity lows. A two-dimensional analysis of the major low, which occurs over the graben and has an amplitude of about −25 milligals, indicates that the volcanic rocks near West Fork are about 7,000 feet thick.

P. L. Weis and A. E. Weissenborn have concluded from mapping in the Greenacres and Mt. Spokane quadrangles, Washington, that the Osburn fault probably extends westward beneath the alluvial fill in the Spokane Valley from its last surface exposure near Coeur d'Alene, Idaho. Their conclusion is supported by the structural and stratigraphic discontinuity reflected in the dissimilar rocks on either side of the valley.

In the Pend Oreille area of northern Idaho, J. E. Harrison's studies of Precambrian Belt Series rocks show that regional metamorphic grade increases systematically with stratigraphic depth, from the chlorite-sericite zone at the top to the biotite zone at the bottom. The transition from the chlorite-sericite rocks to completely reconstituted biotite rocks occurs through about 14,000 feet of section. Preliminary calculations suggest that the transition took place under an increase in load pressure of about 1 kilobar and an increase in temperature of about 140°C.

Geologic and geophysical studies in central Idaho

In the Riggins area of west-central Idaho, mapping by W. B. Hamilton has shown that a Late Jurassic orogen of metamorphic rocks, stocks, and small batholiths trends northeastward into a younger complex formed by the north-trending west margin of the Idaho batholith and its broad border zone of schist and gneiss. The intrusion of the Idaho batholith and the accompanying metamorphism occurred in middle Cretaceous time, and the Jurassic orogen was truncated obliquely, overthrust from the east, and remetamorphosed during the Cretaceous orogeny.

In the Big Creek quadrangle, B. F. Leonard (Art. 5) has mapped epidote-amphibolite facies of metavolcanic rocks that include mafic schists, felsic hornfels with relicit phenocrysts, and reconstituted elongate-pebble breccias and conglomerates. These metavolcanic rocks represent flows, tuffs, and volcanic breccias of Belt(?) age that were intruded by a syenite complex, perhaps of Paleozoic age, and were isoclinally folded before emplacement of the Idaho batholith. The sequence of rocks resembles in some respects the Precambrian coarse clastic rocks and greenstones and Cambrian quartzite of northeastern Washington and southeastern Idaho, and represents a group of rocks that had not been recognized before in central Idaho. The syenites that intruded the metavolcanic rocks are saturated, alkalic varieties that in places contain rare earths and niobium in accessory minerals; location of the rocks may thus be useful in prospecting for rare-earth and niobium deposits in bedrock or in placers.

The southwest face of the Beaverhead Range in the northern part of the Leadore quadrangle is bounded by a zone of generally northwest-trending range-front faults; according to E. T. Ruppel, this zone of frontal faults is cut by nearly vertical north-trending faults that have an apparent horizontal displacement of a few hundred feet to as much as 6,000 feet. The latest movements on both sets of faults have displaced Quaternary alluvial deposits as well as older rocks, and clearly indicate rather recent tectonic activity. The frontal faults are part of a major system of faults that define the Lemhi Valley in the Leadore quadrangle and adjacent areas, and are reflected by steep gradients in gravity anomalies along the mountain fronts. W. T. Kinoshita has made a brief gravity survey of the Lemhi Valley in this area and has found that a major gravity low extends southeast from the vicinity of Leadore to near Nicholia; he infers that the bedrock surface in the center of the valley lies at a depth of about 9,000 feet.

Geologic and geophysical studies in western Montana

In a reconnaissance study of the Centennial Valley in southwestern Montana, W. B. Myers and W. B. Hamilton have recognized the much-deformed shoreline of a large lake that filled the valley in latest Pleistocene or early Recent time. The shoreline cuts talus of late Pinedale (very late Wisconsin) age, yet despite this youth it is warped as much as 60 feet and is broken by fault scarps 10 to 20 feet high. This deformation changed the drainage outlet of the lake from the northeast to the west end of the valley, and drained the lake down to the level of the present small Red Rock Lakes.

Reconnaissance by Hamilton has also shown that the south end of the Madison Range, near Targhee Pass, is underlain partly by tuffs and flows that contain pollen genera and species considered by E. B. Leopold as of probable Oligocene age (Art. 10). These tuffs and flows overlie rocks that range from middle(?) Precambrian to Early Cretaceous in age, and are in turn overlain by rhyolite tuffs of Pliocene(?) and Pleistocene age.

In the Tepee Creek quadrangle, I. J. Witkind (Art. 3) has mapped two parallel bedding faults that are similar in many respects to the detachment faults of northwestern Wyoming, and that may have formed at about the same time and from the same upland. Although little is yet known about direction of movement of the Tepee Creek faults, their similarities with the Wyoming detachment faults suggest that movement on the Tepee Creek faults was southwestward from a break-away point possibly near an ancestral high near the north edge of Yellowstone National Park. The age of the faults has been provisionally determined as post-Early Cretaceous and pre-early Eocene.

Between Divide and Silver Star, south of Butte, Mont., H. W. Smedes and M. R. Klepper have shown that the contacts between pre-Belt metamorphic rocks and younger rocks, including both Belt rocks and, in places, Paleozoic rocks, are thrust faults rather than depositional contacts as earlier considered. At least two major thrust faults are present, both of them older than the rocks of the Boulder batholith. Recent mapping by Klepper has also shown that the steeply dipping pre-batholith fault that bounds the Boulder batholith on the east for 45 miles north of Big Pipestone Creek is preserved south of Big Pipestone Creek in a discontinuous screen of metamorphosed Upper Cretaceous volcanic rocks and Cambrian sedimentary rocks between two major plutons of the batholith.

In the Boulder and Whitetail Valleys, south of Boulder, Mont., gravity measurements by W. T. Kinoshita suggest that the sedimentary deposits in these valleys are little more than a few thousand feet thick, and that the fault-bounded trough in the southern part of the Boulder Valley is relatively shallow. Similarly, aeromagnetic and gravity studies by Kinoshita and W. E. Davis in the Clarkston Valley and in the southwestern arm of the Townsend Valley suggest the presence of a few thousand feet of valley-filling sedimentary deposits, and place the bedrock several thousand feet higher than that underlying the main part of the Townsend Valley.

In the Maudlow area, B. A. Skipp has recognized that part of the Livingston Formation consists of primary volcanic rocks erupted from a local source. The Maudlow area is thus another source for some of the younger epiclastic volcanic debris of the Livingston Formation in the Crazy Mountains basin to the east.

In the Wolf Creek area, the upper part of the Two Medicine Formation of Late Cretaceous age consists mainly of clastic volcanic rocks and lava flows. Conglomerate beds in this sequence contain abundant pebbles and cobbles of welded tuff that R. G. Schmidt, M. R. Klepper, and H. W. Smedes consider megascopically similar to welded tuffs in the Elkhorn Mountains Volcanics in their type area about 50 miles farther south. The similarity of the welded tuffs suggests that at least some, and perhaps most, of the clastic volcanic rocks of the Two Medicine Formation have been derived from the Elkhorn Mountains Volcanics.

Geologic and geophysical studies of the Bearpaw Mountains, Montana

In the southeastern Bearpaw Mountains, detailed geologic mapping by W. T. Pecora and B. C. Hearn, Jr., of a belt of intrusions and deformed sedimentary rocks almost devoid of intrusions, has supported previous conclusions that recurrent collapse is a dominant structural factor in those areas now underlain by volcanic rocks.

Analysis of magnetic-property data from igneous rocks by K. G. Books indicates that both the older volcanic rocks and the intrusive rocks in the Bearpaw Mountains of Montana acquired their permanent magnetization in a field significantly different from the present geocentric dipole field. The paleomagnetic pole position for the mean geocentric dipole field calculated for the older volcanic rocks of Eocene age is at lat 57° N., long 157° E. In terms of the earth's magnetic poles it is a north magnetic pole in the northern hemisphere. The paleomagnetic pole position calculated for the intrusive rocks of Eocene age is at lat 66° N., long 131° W. and is a south magnetic pole in the northern hemisphere. Both of the paleomagnetic pole positions calculated are in general agreement with Eocene pole positions computed by others from European and North American data.

Geologic and geophysical studies in parts of southeastern Idaho, Wyoming, and South Dakota

Alkali basalts of three different ages and chemical compositions have been recognized in the Soda Springs quadrangle, southeastern Idaho, by F. C. Armstrong. A plot of the chemical composition of some of them falls along the differentiation path of the intermediate ankaramite basalt series postulated by K. J. Murata.[30] These data thus support the idea of an intermediate differentiation series and help define its path into the more magnesia-rich ankaramite end of the series. The middle member of the differentiated sequence has a chemical composition similar to that of the Snake River basalt clan identified by H. A. Powers, which suggests that the Snake River basalts may also belong to the ankaramite differentiation series. These suggested conclusions are tentative as they are based on only a few chemical analyses and on samples from a small part of the total amount of basalt in the area.

Field studies by W. C. Culbertson have demonstrated that the Tower Sandstone Lentil of the Green River Formation in the Green River area, Wyoming, is not a single bed as earlier supposed, but rather is a series of lenses occurring at many horizons in the lower 400 feet of the Laney Shale Member (Art. 78). The Tower

[30] Murata, K. J., 1960, A new method of plotting chemical analyses of basaltic rocks: Am. Jour. Sci. Bradley Volume, v. 258-A, p. 247-252.

Sandstone Lentil is therefore abandoned. Culbertson has also noted that two oil-shale zones near the base of the Laney Shale Member locally have potential oil yields that are high enough to be of possible future commercial value.

In the vicinity of Jackson, Wyo., studies by J. D. Love show that the Quaternary rocks have been deformed as a result of crustal adjustments, and that one of the youngest Quaternary units, a loess that is believed to be 10,000 to 20,000 years old, has been downdropped at least 200 feet (Art. 160). Mild earthquakes are common in this area, and it seems likely that the crustal adjustments are continuing and should be considered in the planning, design, and location of major construction projects.

Surface and subsurface studies by W. R. Keefer and J. D. Love of lower Eocene rocks along the north and east margins of the Wind River Basin, Wyo., indicate the presence of three distinct stratigraphic units. The oldest of these was overridden by major reverse faults along the south margin of the Owl Creek Mountains and the west margin of the Casper arch. The other two units were deposited after the faulting had taken place, and reflect only the slight to moderate folding of the basin margins in post-early Eocene time. A parallel structural history for the Granite Mountains is suggested by surface work and drilling which show that a thrust sheet of Precambrian rocks moved southward over a thick sequence of earliest Eocene rocks.

In his study of the origin of detachment faults in northwestern Wyoming, W. G. Pierce had shown that the South Fork fault is older than the Reef Creek fault. Pierce's earlier work[31] had shown that the Heart Mountain fault was younger than either the South Fork or Reef Creek faults, but the relative age of the last two faults was unknown. By mapping the "early acid breccia" unit, he has been able to determine the relative ages of these two faults, and to confirm that the volcanic source of the breccia probably was north-northwest of its presently known occurrence.

Study of crossbedding in the Lakota Formation of Cretaceous age in part of Wyoming and South Dakota by W. J. Mapel and C. L. Pillmore has indicated probable deposition by meandering streams with general northward flow (Art. 13).

Mapping of Precambrian rocks in the central Black Hills, S. Dak., by J. C. Ratté, has shown the presence of a shear zone about half a mile wide trending N. 34° W. across the northeastern corner of the Hill City quadrangle. The zone, which cuts across the general north to northeast trend of structures in the rest of the quadrangle, consists of a number of narrow shears that contain a few small quartz veins.

[31] Pierce, W. G., 1960, Reef Creek detachment fault in northwestern Wyoming [abs.]: Geol. Soc. America Bull., v. 71, no. 2, p. 1944.

Stratigraphic studies of Paleozoic rocks

Stratigraphic and faunal studies by J. T. Dutro, Jr., and W. J. Sando of a Mississippian sequence in the Chesterfield Range, southeastern Idaho, provide a key to the nature of rocks previously called Brazer in this area. Two new formations are recognized: a 1,000-foot-thick clastic sequence below and a 900-foot-thick carbonate sequence above. The clastic sequence is divided into a sandstone member overlain by a sandy limestone member. The carbonate sequence is divided into the following three members, from bottom to top: massive limestone, medium-bedded limestone, and cherty limestone. Three faunal-assemblage zones are also recognized, the lower two of which are probable Meramec equivalents and the upper of which is apparently of Chester age.

Studies of regional Devonian stratigraphy by C. A. Sandberg suggest that the Englewood Limestone may be partly of Late Devonian age in the Black Hills, rather than entirely of Early Mississippian age. A local angular unconformity between the Englewood and the overlying Pahasapa Limestone suggests that the earliest Mississippian orogeny of the Williston Basin area extended at least as far south as the northern Black Hills.

Stratigraphic studies of Permian rocks in Wyoming by E. K. Maughan have shown that carbonate rocks of Permian age in the Owl Creek Mountains of central Wyoming are transitional from laminated argillaceous dolomite in the east, through oolitic and pelletal limestone (bahamaite), to richly organic skeletal limestone in the west. The dolomite facies is believed by Maughan to have been deposited in a lagoon environment, the oolitic and pelletal limestone in an offshore bar environment, and the skeletal limestone on the seaward side of the offshore bars.

Stratigraphic studies of Mesozoic rocks

A distinctive ostracode species, previously known only from Wyoming, has been noted by I. G. Sohn in the lower part of the Morrison Formation of Montana and in the Salt Wash Member of the Morrison Formation in Colorado. This suggests the possible extension of Salt Wash equivalents to Wyoming and Montana.

Stratigraphic studies of rocks of the Montana Group of Cretaceous age in the southern half of Wyoming by A. D. Zapp (Art. 134) have shown that tongues of nonmarine and marine strata reflect five significant regressive-transgressive cycles. Associated fossils and lateral tracing serve to establish the correlation of more of these tongues with those recently described in northwestern Colorado and northeastern Utah.[32] Two local unconformities within the rocks of the Montana Group were recognized near the point common to Sweetwater, Fremont, and Carbon Counties, Wyo. One is at the base of the Lewis Shale; the other is in the lower part of the Montana Group.

C. F. Dyer and A. J. Goehring found that the Dakota Sandstone of the type area in northeastern Nebraska, southeastern South Dakota, and northwestern Iowa grades westward into the Mowry Shale and Newcastle Sandstone in the Black Hills area. A few tens of miles east of the Black Hills the sandstones and shales of the Inyan Kara Group thin and the Newcastle Sandstone apparently thickens at the expense of the intervening Skull Creek Shale. Near Chamberlain in central South Dakota the Skull Creek becomes very thin and the Dakota Sandstone apparently merges with the uppermost sandstone of the Inyan Kara Group. The lowermost sandstone of the Inyan Kara probably is not present east of a line between Chamberlain and Aberdeen, S. Dak.

As a result of field investigations by J. R. Gill in the western part of the Powder River basin, Wyoming, and in central and western Montana, study is nearly completed of an east-west section across the north-trending Late Cretaceous Pierre seaway, from the stable eastern shelf area to the Late Cretaceous land area in western Montana. In the center of the seaway, the deposits consist of westward-thickening wedges of marine regressive sandstone separated by westward-thinning wedges of marine shale, with each wedge representing a major change in the position of the western strand line. Further west, regressive marine deposits give way to thick brackish-water beds or entirely non-marine beds that contain an abundance of volcanic material. From east to west the marine transgressive deposits thin, become more sandy, contain much volcanic material and finally merge into brackish-water and non-marine deposits.

Ground-water investigations in Montana

A study by L. J. Hamilton has revealed that water is under artesian pressure in the alluvial gravel underlying the irrigated central part of the Bighorn Valley. The principal recharge to this aquifer is leakage from a canal along the lower part of a scarp rising to a higher terrace. Artesian pressure prevents downward percolation of irrigation water, thus causing waterlogging and salt accumulation on the poorly drained clayey alluvium. Additional waterlogging may occur in the future if higher terraces are extensively irrigated, unless provision is made to intercept and control ground-water discharge.

[32] Zapp, A. D., and Cobban, W. A., 1960, Some Late Cretaceous strand lines in northwestern Colorado and northeastern Utah: Art. 112 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B246–B249.

Investigation of the Bluewater Springs area, Carbon County, by Everett Zimmerman indicated that water from many springs and one flowing well apparently comes from the Tensleep Sandstone and the Chugwater Formation. Leakage from the Madison Limestone probably supplies some water to these aquifers. Springs from the Tensleep generally are along fault lines; those from the Chugwater issue from joints. These sources are believed adequate to supply additional water needed for a proposed Federal fish-rearing station.

An investigation by Everett Zimmerman revealed that the southern Judith Basin is underlain by several artesian aquifers. The shallowest of these—the Kootenai Formation of Cretaceous age—yields natural flows of as much as 100 gpm of soft water to some wells. Oil tests indicate that deeper artesian aquifers contain water of poor quality. Domestic and livestock supplies are obtained principally from terrace deposits and alluvium, which yield water of good quality but harder than that from the Kootenai.

Ground-water investigations in Wyoming

An investigation in Sheridan County and northern Johnson County by M. E. Lowry and others indicated that small supplies of ground water can be obtained from beds of sandstone and coal in the Fort Union and Wasatch Formations of Tertiary age. The pre-Tertiary formations are deeply buried throughout most of the area; however, many wells penetrating these formations in the outcrop area flow, and as much as 600 gpm has been pumped from the Tensleep Sandstone. The alluvium yields small quantities of water.

C. E. Sloan's reconnaissance hydrogeologic study of the Desert Grazing Unit, in the northern part of the Bridger Basin, Wyo., shows that ample supplies of stock water can be developed from shallow depths in the alluvium of larger stream valleys. Wells in the upland areas generally can obtain supplies at depths of less than 300 feet from the Wasatch and Green River Formations of Eocene age. In local areas of high topographic relief, where the depth to ground water is excessive, reservoirs to collect and store storm-water runoff afford a practical source of stock water.

Ground-water investigations in North Dakota

Studies by P. G. Randich revealed that relatively large quantities of ground water are available in aquifers beneath terraces along the east side of the Missouri River near Bismarck, N. Dak., and in buried glaciofluvial deposits in south-central Burleigh County.

H. M. Jensen reported that test drilling in northern Traill County revealed only small supplies of ground water of relatively poor quality in the glacial drift.

Studies by C. J. Huxel, Jr., indicated that in Stutsman County large supplies of ground water are obtainable from outwash plains, valley outwash, and buried preglacial or interglacial channels that contain stratified sand and gravel.

Ground-water investigations in South Dakota

An investigation by C. F. Dyer and M. J. Ellis revealed that pre-Cretaceous rocks yield large supplies of good-quality water to flowing and nonflowing artesian wells in and near the outcrop area surrounding the Black Hills. These rocks underlie much of western South Dakota, but only a few wells outside of the Black Hills area are known to obtain water from them. Records of oil tests and a few water wells indicate that the Mississippian Mission Canyon Limestone and the Ordovician Red River Formation probably are the major untapped sources of water in a large part of western South Dakota.

SOUTHERN ROCKIES AND PLAINS REGION

Geologic and hydrologic investigation in the Southern Rockies and plains region during the fiscal year 1962 led to advances in the several fields summarized below. Additional information on the region is included under other headings in this report: mineral deposits, pages A4 and A5; coal deposits, page A11; paleontology, page A74; major crustal studies, page A84; ore-solution studies, Creede, Colo., page A89; potassium-argon age determinations, page A94; lead-alpha age determinations, page A94; lead-isotope studies, page A96; ground water, Kearney, Nebr., page A110.

Geology of Precambrian rocks

Current knowledge of the two stages of folding recognized in the Precambrian rocks of the Idaho Springs–Central City area in the Front Range west of Denver, Colo., has recently been summarized by R. H. Moench, J. E. Harrison, and P. K. Sims (1962). Continuing studies by R. B. Taylor, W. A. Braddock, and P. K. Theobald, have shown that these 2 stages of deformation are recognizable across the entire 40-mile width of the range, and moreover, that each stage is characterized by intrusive igneous rocks similar to those of the Idaho Springs–Central City area.

D. J. Gable has recently discovered that cordierite is a widespread constituent of gneisses in the vicinity of diorite and granodiorite bodies in the Central City quadrangle. The diorite and granodiorite are related to the Boulder Creek Granite, the older of the two main classes of igneous rocks recognized in this part of the Front Range. The cordierite occurs in biotite gneiss that contains sillimanite, garnet, a little spinel, and erratically distributed microcline. This assemblage suggests a more intense metamorphism than had previously been recognized in these rocks.

P. K. Sims and R. B. Taylor (Art. 154) report the discovery of hypersthene gabbro, a mafic intrusive rock not previously known in the Front Range. The gabbro forms subconcordant plutons southwest of Fraser, Colo., and a phacolithic body near Apex, north of Central City. It is a product of the same period of Precambrian intrusion as the granodiorite of the Boulder Creek, but younger than the granodiorite. Near Fraser, the gabbro transformed adjoining biotite gneiss to rocks of the pyroxene hornfels facies of metamorphism, and locally melted the gneisses, forming hornfelsic contact breccia.

Near the mountain front, Boulder Creek Granite and a related but younger quartz monzonite along the southern end of the Boulder Creek batholith have an anticlinal internal structure. Studies by J. D. Wells have shown that the southeastern flank of the anticline is defined by a foliation produced principally by cataclasis, and the northwestern flank by a foliation produced by igneous flow. The foliations are apparently contemporaneous, and they formed at a stage when an outer shell of the batholith was solid enough to fracture, and the inner part was liquid enough to flow.

M. C. Van Lewen reports that a well for disposal of chemical wastes at the Rocky Mountain Arsenal, Derby, Colo., was completed at a depth of 12,045 feet. The well, the deepest ever drilled in the Denver Basin, entered fractured Precambrian biotite granite gneiss at 11,974 feet. A sequence of orange quartzite, maroon shale, and pink to white dolomite, probably of Cambrian or Ordovician age, was penetrated between 11,895 feet and the contact with the Precambrian.

The Silver Plume Granite, which is younger than the Boulder Creek Granite and related granodiorite, forms a large pluton in the west-central part of the Front Range, near Berthoud Pass. Studies by P. K. Theobald indicate that the pluton is composite and is made up of three texturally different varieties of the granite, which were intruded in sequence. A pegmatite zone more than 3,000 feet wide and 10,000 feet long lies near the northern edge of the pluton, near Winter Park. The pegmatite is mineralogically simple and contains many large inclusions of gneiss, but it may have commercial value as a source of scrap mica.

Precambrian rocks in the western part of the Poncha Springs quadrangle, near Salida, Colo., have been found by R. E. Van Alstine to include mica schist, biotite gneiss, hornblende gneiss, marble, quartzite, and calc-silicate rock. Farther east, near a mafic intrusive body, dark gneisses made up principally of magnesian silicate minerals predominate. The gneisses enclose large sill-like bodies of granitic rock, and smaller bodies of pegmatite that contain muscovite, tourmaline, and beryl. The sulfide minerals chalcopyrite and sphalerite occur in replacement deposits in the schists and gneisses. Immediately east of the quadrangle these sulfide minerals also occur in quartz veins that contain scheelite.

Stratigraphic and paleontologic studies

The coarsely clastic Minturn and Maroon Formations of Pennsylvanian and Permian age are separated by the Jacque Mountain Limestone Member of the Minturn. In the northwest part of the Minturn quadrangle, Colorado, where slumping and cover obscure the geologic relations, dailed study by T. S. Lovering and W. W. Mallory showed that all three of these units intertongue with gypsum and gypsiferous mudstones. This evaporitic equivalent of part of the Maroon and Minturn has been named the Eagle Valley Evaporite (Art. 132).

Sedimentary structures in certain rocks of the Boulder quadrangle, Colorado, have been studied by R. F. Wilson to determine the origin of the rocks and the direction to their source. The Lyons Sandstone, of Permian age, was deposited largely as sand dunes by winds blowing in a southerly direction. The uppermost member of the overlying Lykins Formation (Permian? and Triassic?) was deposited by confined and unconfined water currents flowing in a northeasterly direction. The lower sandy part of the Morrison Formation, of Late Jurassic age, was deposited by streams flowing in a northeasterly direction, and at least a part of the Fountain formation (Pennsylvanian and Permian) had a similar northeasterly direction of transport.

Marine Jurassic deposits and some accompanying Upper Triassic rocks in a triangular area extending from Boulder, Colo., northward and northwestward to Douglas and Lander, Wyo., are currently under study by G. N. Pipiringos. Near Lander, the thickness of Triassic and Jurassic rocks between the Alcova Limestone Member of the Chugwater Formation, of Triassic age, and the Morrison Formation, of Late Jurassic age, is about 1,000 feet. This sequence thins eastward to about 300 feet near Douglas, and it thins southward to about 35 feet near Boulder. The Jelm Formation (Upper Triassic) of southeastern Wyoming has been traced into the Lander area, where its upper member is overlain by the lower part of the Popo Agie Member of The Chugwater Formation (Upper Triassic) without intertonguing. Similarly, the Nugget Sandstone (Lower Jurassic) of the Lander area overlies the Popo Agie without the intertonguing sometimes ascribed to these formations. A disconformity separates the lower or Callovian part of the Sundance Formation (Upper Jurassic) from the upper or Oxfordian part. Farther south in Colorado, in the Trinidad coal field, R. B. Johnson has found a sequence of gypsum and limestone lying between the Entrada Sandstone (Upper Jurassic) and the fluvial deposits typical of the Morrison Formation (Art. 77).

Detailed paleontologic and stratigraphic studies of the Niobrara Formation (Upper Cretaceous) at Pueblo, Colo., have led G. R. Scott and W. A. Cobban to divide the formation into eight members. Each member is identifiable both by lithology and by fossils. Twelve faunal zones are recognized in the Niobrara Formation. Genera of *Inoceramus* and *Scaphites* predominate, but other genera have equal value as guide fossils. The ammonite *Haresiceras* indicates that the upper part of the formation at Pueblo is Campanian in age (Art. 22). *Clioscaphites saxitonianus* was found to form a separate scaphite zone rather than to occur with *C. vermiformis* as formerly supposed (Art. 90). In work on the Niobrara Formation farther south, C. H. Dane and W. A. Cobban found that glauconitic sandstone of early Niobrara age in Rio Arriba County, N. Mex., grades northward into limestone typical of the Fort Hays Limestone Member of the Niobrara Formation near Pagosa Springs, Colo. Dane has also found that unconformity between rocks of Carlile and Niobrara age extends farther south on the east side of the San Juan basin in New Mexico than believed previously, although the geographic limits have not yet been defined.

Study of the stratigraphy and paleontology of the Pierre Shale (Upper Cretaceous) in eastern Colorado is being made by W. A. Cobban and G. R. Scott. Near Pueblo, the base of the Pierre Shale contains the zone of *Baculites* cf. *aquilaensis* and the upper half of the zone of *Scaphites hippocrepis*. The base of the Sharon Springs Member of the Pierre Shale in this area is coincident with the base of the zone of *Scaphites spiniger*.

The Green Mountain Formation of LeRoy [33] in Jefferson County, Colo., has been found by J. H. Smith to be predominantly sandstone, siltstone, and claystone, rather than conglomerate as previously supposed. Plant fossils from a claystone 100 to 150 feet above the base of the formation have been provisionally dated by H. D. MacGinitie of Humboldt State College, Calif., as not younger than Paleocene.

In Valley County, Nebr., R. D. Miller and T. C. Nichols have found terrace-like erosion surfaces at three levels beneath a cover of the Loveland, Peorian, and Bignell Loesses. The erosion surfaces mark stages of

[33] LeRoy, L. W., 1946, Stratigraphy of the Golden-Morrison area, Jefferson County, Colorado: Colorado School Mines Quart., v. 41, no. 2, p. 101, 111–113.

valley cutting in pre-Illinoian time, probably during the early Pleistocene. In the Golden quadrangle, Colorado, a sequence of soils and erosion surfaces has been found by Richard Van Horn to represent most of Pleistocene and Recent time. A volcanic ash in this sequence has been correlated with ash of late Kansan age in Kansas, and it thus provides a stratigraphic tie with the standard Pleistocene sequence of the Plains region. A few miles south of the Golden quadrangle, a remarkable deposit of vertebrate fossils and associated artifacts of early man is under study by G. E. Lewis in company with members of the U. S. National Museum. The fossiliferous deposit was the site of a bog in which many animals became mired in late Wisconsin time. More than a ton of fossils, principally of mammoth and bison, has been collected and is being prepared for study.

Geology of volcanic terranes in Colorado and New Mexico

Further study of the volcano-tectonic depression occupied by the Silverton and Lake City calderas of the western San Juan Mountains, Colo., has been made by W. S. Burbank and R. G. Luedke, and a map of one of the quadrangles bordering the depression has been published (Luedke and Burbank, 1962b). Recent findings indicate that the mass of Precambrian granite between the two calderas is not a fault block as previously mapped but an ancient hill within the volcano-tectonic depression. This hill guided the movement of volcanic materials in the central part of the depression. Large volcanic domes within the peripheral ring-fault zone of the volcano-tectonic depression were extruded after the subsided core of the depression was domed. Similar relations have ben observed in the Creede caldera to the east by T. A. Steven and J. C. Ratté. Recent studies by Steven and Ratté show further that several ash-flow sheets related to the Creede caldera formed from successive ash flows that accumulated so rapidly near the source that they welded together to form single cooling units, whereas toward the margins they formed multiple cooling units. They are thus composite ash-flow sheets according to the classification of R. L. Smith.[34]

In the Powderhorn district, near the northern margin of the San Juan volcanic field, J. C. Olson and D. C. Hedlund have found that several welded and nonwelded tuff units of probably Miocene age rest on older Tertiary laharic breccias, Mesozoic sedimentary rocks, and Precambrian rocks. On the south side of the Gunnison River, the ash flows dip about 2° N., but on the north side they dip gently southward, parallel to the surface on which they were deposited. In contrast, the underlying Mesozoic rocks dip gently northward on both sides of the river.

[34] Smith, R. L., 1960, Ash flows: Geol. Soc. America Bull., v. 71, p. 795–842.

Volcanic flows and thick masses of volcanic breccia in the Rabbit Ears Range, between Middle Park and North Park, Colo., have been found by W. J. Hail to be basaltic and andesitic in composition. Dikes and pluglike masses that probably were feeders for the volcanic rocks are mainly andesitic and dacitic, as are associated sills. Some of the sills are greatly thickened at their updip margins, and the prominent peaks of the western part of the range were carved from them.

Continuing studies of the Valles caldera in the Jemez Mountains, N. Mex., by R. L. Smith and R. A. Bailey have provided new evidence on the nature and timing of caldera collapse. Although the collapse resulted from extrusion of the great volume of rock classed as Bandelier Tuff, distribution of the upper ash-flow unit of this tuff indicates that the subsidence did not occur until after all the tuff had been extruded. Thus there was no gradual subsidence concurrent with eruption, but rapid subsidence after eruption ceased. This suggests that some force existed temporarily to support the roof of the partially emptied magma chamber until eruption ended.

Studies of intrusive igneous rocks in Colorado

The Empire stock in the Front Range west of Denver has been found by W. A. Braddock to be a composite body made up of four kinds of rock, each of which was intruded separately. From oldest to youngest, these rocks are nepheline-bearing pyroxene monzonite, pyroxene-hornblende mozonite, leucocratic quartz-bearing monzonite, and porphyritic adamellite or granite. The stock, of Laramide age, caused marked contact metamorphism of the Precambrian wallrocks and xenoliths. Cordierite formed in some rocks; biotite broke down to an aggregate of sanidine, corundum, and magnetite; and perthitic microcline was transformed to untwinned nonperthitic orthoclase.

Stocks in the San Miguel Mountains of southwestern Colorado also are composite. The Mt. Wilson stock, studied by C. S. Bromfield, consists of microgranogabbro, granodiorite, and quartz monzonite, intruded in that order. The nearby Dolores Peaks stock, studied by A. L. Bush and C. S. Bromfield, consists of an older granodiorite and a younger quartz monzonite. Tuffaceous volcanic rocks recently found near the western edge of the stock may be related to two pipelike bodies of quartz latite that cut the granodiorite.

Dating of Laramide features

In the Leadville area, Colorado, most of the known faults formed during the part of the Laramide orogeny when porphyries of many kinds were intruded. Ages of the oldest and one of the youngest porphyries have been determined by R. C. Pearson and others (Art. 87), using the potassium-argon method. If correct, the age figures indicate that in the Leadville area the climax of the Laramide orogeny, marked by porphyry intrustion and the formation of faults, occurred in the interval between 64 and 70 million years ago.

Aerial radioactivity survey in Colorado

An aerial radioactivity survey of 6,000 traverse miles at 1-mile spacing was made immediately east of the Front Range, Colo., by J. A. MacKallor. In most of the area, radioactivity is between 650 and 1,000 counts per second, and there is little correlation between bedrock and radioactivity. Radiation highs of 1,000 to 1,400 cps are correlated with rhyolite flows near Castle Rock, and with granitic alluvial material derived from the Front Range.

Ground-water recharge

About 12,000 acres in the Mirage Flats area in northwestern Nebraska was irrigated with water diverted from the Niobrara River in 1961, according to C. F. Keech. Because of infiltration of part of the irrigation water, ground-water levels have risen. About 50 irrigation wells have been installed to supplement the supply of surface water.

Little if any precipitation on Frijoles Mesa, N. Mex., percolates through the soil mantle into the underlying tuff, and the infiltration of arroyo flow on the mesa is negligible after bank and channel material become saturated, according to J. E. Weir, Jr., and W. D. Purtyman. During arroyo flow, the moisture content increased in the channel material and underlying tuff to a depth of 3.5 feet but decreased rapidly after the flow ended, owing to evaporation and to capillary return to the surface. The large number of open joints, mapped in large-diameter drill holes by special techniques (Baltz and Weir, 1961), are the dominant factors influencing the permeability of the Bandelier Tuff.

Ground-water storage

An additional 18,000 acre-feet of water can be pumped annually from the Arikaree Formation in the Wheatland Flats area, Wyoming. E. P. Weeks reports that (a) the pumping lift under the new equilibrium conditions resulting from the additional pumping would range from about 185 to 190 feet, and that (b) the flow in the Laramie River eventually would be reduced 6,000 to 7,000 acre-feet per year.

An analysis by G. E. Welder of the results of test-hole drilling in the vicinity of Glendo, Wyo., indicates that the Hartville Formation is incapable of yielding large quantities of water to wells for irrigation and that Recent stream deposits in parts of the area are capable of yielding only moderate amounts of water to wells.

Formation and deposition of clay balls, Rio Puerco, New Mexico

The environment of the Rio Puerco in New Mexico is ideally suited to the formation of clay balls, according to C. F. Nordin, Jr., and W. F. Curtis (Art. 14). They found numerous clay balls in a reach of the Rio Puerco near Bernardo in 1961. All the balls exhibited a high degree of sphericity. Some were armored and others were not. Most had no perceivable internal structure, whereas other had various types of structure—concentric, laminated, and composite. Cores having structure must have been dry during transportation, otherwise plastic deformation would have distorted or destroyed the structure.

COLORADO PLATEAU REGION

Geologic and hydrologic work in the Colorado Plateau region during fiscal year 1962 has yielded significant results in the fields of stratigraphy and paleontology, structural history, emplacement of igneous rocks, rock alteration, physiography, ground water, and surface water. Some of these results are summarized below. Others are reported as follows: uranium deposits, page A8; thorium-bearing veins, page A9; coal resources, page A11; paleontology, page A75; geomorphology, page A76; rock mechanics in mining, page A106; and botanical studies, page A115.

Stratigraphy and paleontology

As part of the study of the Redwall Limestone in the Grand Canyon region, Arizona (see McKee[35]), J. T. Dutro, Jr., has analyzed the brachiopod fauna and B. A. L. Skipp is analyzing the Foraminifera. Dutro reports that most of the formation can be correlated with upper Kinderhook and Osage (Early Mississippian) equivalents elsewhere; that Meramec (Late Mississippian) faunal elements are found in the upper part of the Redwall in the western Grand Canyon region; and that an assemblage of Chester age (late Late Mississippian) occurs at one locality in beds immediately overlying the Redwall. Skipp reports the identification of the following stratigraphically restricted genera of calcareous Foraminifera, previously described only from Lower Carboniferous rocks of the Soviet Union: *Carbonella* Dain 1953, *Chernyshinella* Lipina 1955. *Septaglomospiranella* Lipina 1955, *Septatournayella* Lipina 1955, and *Tournayella* Dain 1953.

W. J. Sando has recognized several marker coral horizons in the Lower Mississippian Redwall Limestone of northern Arizona. The upper part of this formation locally was eroded or telescoped by solution and

[35] McKee, E. D., 1960, Lithologic subdivisions of the Redwall Limestone in northern Arizona—their paleogeographic and economic significance: Art. 110 *in* U.S. Geol. Survey Prof. Paper 400-B, p. B243-B245.

collapse prior to Pennsylvanian deposition. A residuum containing silicified corals from the Redwall was reworked by the Pennsylvanian sea. The lower two members of the Redwall were not recognized south of the Defiance uplift.

In a compilation and analysis of findings at Circle Cliffs, in south-central Utah, E. S. Davidson has found that major channel systems of the Shinarump Member of the Chinle Formation, of Triassic age, extend as much as 10 miles and may be inferred to extend another 10 miles. Parts of the channel system are logical targets for uranium prospecting.

In his study of the San Rafael Group of Jurassic age, J. C. Wright has recognized an ancient barrier beach that separates a marine facies characteristic of the Carmel Formation from a littoral facies characteristic of the Entrada Sandstone. The barrier beach, which lies south of Green River, Utah, comprises lenses of sandstone 5 to 15 feet thick and 1,000 to 3,000 feet broad. Pale-reddish-gray limey clay-shale west of the beach grades within 2 to 4 miles to greenish-gray limestone that contains marine fossils and is typical of the Carmel Formation. Massive reddish-brown siltstone east of the beach is a facies of the lower part of the Entrada Sandstone.

Recent work by J. R. Donnell indicated that red claystone beds and lenticular sandstone beds similar to the fluviatile Wasatch and Bridger Formations overlie the uppermost lacustrine beds of the Green River Formation at one locality near the southeast corner of Grand Mesa, Colo. This is the only place in the Piceance Creek basin where beds of the Wasatch or Bridger have been found overlying the upper part of the Green River Formation.

The Burro Canyon Formation is widely distributed in the central and northeastern parts of the plateau. The upper part of the formation has been well-dated as Early Cretaceous by Simmons.[36] The age of the lower part of the formation, however, has been in doubt. R. B. O'Sullivan recently obtained fossils from the Karla Kay Conglomerate, locally the basal member of the Burro Canyon. The fossils, examined by R. A. Scott and D. W. Taylor, indicate that the Karla Kay is of Early Cretaceous age.

The Salt Wash Member of the Morrison Formation, one of the principal host rocks of uranium deposits on the Colorado Plateau, has long been known to have been deposited in the form of a gigantic alluvial fan that thins to the northeast. A smaller fan, characterized by a distinct lithology, is superposed on the large one in southwest Colorado. The toe of the smaller fan marks a change in lithology and coincides with the Uravan mineral belt of uranium deposits in southwest Colorado, according to D. R. Shawe (Art. 62). The fan likely resulted from accelerated streamflow caused by local downwarping in Jurassic time.

[36] Simmons, G. C., 1957, Contact of Burro Canyon Formation with Dakota Sandstone, Slick Rock district, Colorado, and correlation of Burro Canyon Formation: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 11, p. 2519–2529.

Structural history

New data on the amount of pre-Tertiary structural movement in the Colorado Plateau has recently become available.

Continued studies of the Carrizo Mountains, Ariz., near the center of the Colorado Plateau by J. D. Strobell indicate that the ridgelike basement "high" recognized earlier is the crest of a tilted fault block. The ridge trends northwest from the mountains and is bounded on the northeast by a fault that has been active intermittently since the Devonian and has possibly existed since Precambrian time. The Ouray Limestone of Devonian age is displaced a total of 1,550 feet by the fault, but stratigraphic changes indicate that this displacement was achieved in steps, as follows: 500 feet in Devonian (Elbert) or pre-Devonian time; 600 feet just prior to or during Pennsylvanian (Paradox) and Permian (Cutler) time; 200 feet in Mesozoic time; 250 feet in Laramide time. During the Laramide orogeny lower beds were faulted, whereas shallower beds were only folded. The ridge may be a northern element of the Defiance uplift, a positive area that existed in northeastern Arizona during Pennsylvanian time. As projected, the ridge would intersect a ridge of northeast trend, also of Pennsylvanian age, beneath the complex of intrusive rocks that underlie the Carrizo Mountains, and this intersection apparently localized the intrusive center. The ridge and its boundary fault influenced migration of oil and gas, helium, and presumably other fluids of deep origin within the Paradox basin. It may be coincidental that a cluster of uranium deposits overlies these deep structures.

At the northeastern edge of the Colorado Plateau, in the Black Canyon of the Gunnison River, Colo., W. R. Hansen has mapped two sets of high-angle faults. One set trends west-northwest, and the other, north to east. One fault of the west-northwest set is more than 20 miles long and an echelon to the great Cimarron fault. Some of the faults of both sets clearly show two periods of movement. The first movement occurred before Jurassic time, perhaps when the Uncompahgre highland was elevated during Pennsylvanian time. This early movement was strike-slip, left lateral on the west-northwest set and right lateral on the north to east set, and displacements are measured in thousands of feet. The second and smaller movement occurred in early Tertiary time, before extensive volcanism began. Movements at this time were vertical, on some faults pivotal, and displacements measure a few hundreds to a few thousands of feet; some faults with large pre-Jurassic displacement pass upward into partly ruptured monoclines of Tertiary age.

At the south-central edge of the Colorado Plateau, in the eastern Mogollon Rim of Arizona, mapping by T. L. Finnell (Art. 143) has also demonstrated two periods of fault movement. A vertical fault trends northward, parallel to one of the dominant structural trends marked by diabase dikes of Precambrian age. The first movement displaced the Martin and Naco Limestones, respectively, of Devonian and Pennsylvanian age, as much as 1,200 feet up on the west. The second movement appears to have displaced gravel and basalt of Tertiary or Quaternary age as much as 1,400 feet down on the west. The fault is probably a member of the Basin and Range structure system that projects into the plateau from the south.

Igneous rocks

In their study of the Ute Mountains of southwest Colorado, E. B. Ekren and F. N. Houser have found intrusive masses in the core of a large structural dome apparently formed by the forceful injection of three stocks.. The alinement of the stocks appears to be controlled by a north-northeast-trending zone of fractures which may reflect structure in the underlying Precambrian rocks. The igneous rocks rich in hornblende, range from gabbro to quartz monzonite. They may have formed as a result of differentiation during crystal settling of a fused and partly fused hornblende substratum.

W. R. Hansen has mapped the Curecanti Granite of Precambrian age in the upper part of the Black Canyon of the Gunnison River, Colo. The pluton is discordant, somewhat mushroom shaped, and about 3½ miles long and 2 miles wide. Undulatory but mainly subhorizontal contacts of floor and roof cut across steeply dipping foliation of the Precambrian metamorphic wallrocks. An exposed thickness of 1,200 feet of granite west of the center of the pluton suggests deep roots there.

Physiography

W. R. Hansen has determined that the impressive gorge of the Black Canyon of the Gunnison River is the result of several geologic events. Following the Laramide orogeny, when the Gunnison uplift was formed, consequent streams flowed westward across the area from the Continental Divide. By about middle Tertiary time, erosion had reduced the area to a nearly flat plane, and streams flowed at random across the underlying structure. Volcanoes building up over the site of the West Elk Mountains crowded the drainage southward against the accumulating San Juan volcanic piles. At the cessation of volcanic activity a syncline formed over the site of the Black Canyon, possibly as a result of subsidence of the West Elk Mountains. The Gunnison River shifted laterally to occupy this syncline, entrenched, and superposed itself through the volcanic and sedimentary rocks onto the hard Precambrian rocks. Meanwhile, rapid degradation of the Mancos Shale in the valleys of the North Fork of the Gunnison and the Uncompahgre River provided the main stem of the Gunnison with the steep gradient needed to cut its canyon into the hard Precambrian core of the Gunnison uplift. The narrowest and most awesome parts of the canyon are incised into granitic rocks that intruded the metamorphic complex.

In parts of the Colorado River system of Arizona and Utah, M. E. Cooley (Art. 18) has found that multiple periods of alluviation, erosion, and terracing record the geologic events of late Pleistocene and Recent time. Although the amount and type of alluviation and erosion vary from one locality to another, the alluvial-erosional sequence generally is similar and is recognizable in many drainge systems.

G. G. Parker reports that in certain arid and semiarid lands, piping is a major factor in the erosive process and plays an important role in the shaping of minor landforms. Also, in some areas, it creates serious land-stability problems. Piping, sometimes called natural tunneling, is the development of subsurface drainage tubes in certain soils or in weakly consolidated shale and silt. Runoff, instead of following surface channels to trunk streams, disappears into the soil through sinkholes, commonly producing a miniature karst topography. An example of this is on the low hills of the Chinle Formation near Chinle and Cameron, Ariz., where the crowns of many hills are sieved with sinkholes into which surface water runs. Discharge is through wet-weather seeps and springs into surface channels at or near the bases of the hills. Rodent holes, root holes, and deep cracks may start pipes in some areas, but in general, pipes seem to develop without initial holes or cracks in the ground.

Hydrologic problems in San Juan County, New Mexico

Ground water of good quality is available only locally in San Juan County, N. Mex., according to F. D. Trauger; although many geologic formations yield ground water in small to large quantities, the water quality generally ranges from poor to unusable for any purpose. Most water used in the county, therefore, is river water.

The three greatest hydrologic problems are alleviation of waterlogging in irrigated areas, locating additional potable ground water in areas distant from rivers, and protection of both surface water and ground water from contamination and pollution. Completion of the Navajo Dam will provide additional surface water and should solve some of the problems.

Hydrogeology near Los Alamos, New Mexico

Hydrogeologic data gathered and analyzed by R. L. Griggs in the Los Alamos area, New Mexico, show that wells drilled into the Santa Fe Group of Middle(?) Miocene to Pleistocene(?) age, yield about 500 gpm (gallons per minute) with a specific capacity of 3 to 7 gpm per foot of drawdown. Thus, several wells properly spaced to minimize pumping interference can supply Los Alamos with adequate water for municipal use.

Much of the Los Alamos area is underlain by tuffaceous rock identified as Bandelier Tuff. According to Griggs, the tuff comprises the following members in a ascending order: (1) Guaje Member, an unconsolidated deposit of pebble-sized pumice; (2) Otowi Member, a massive aggregate of poorly sorted, pumiceous, rhyolite-tuff breccia; and (3) Tshirege Member, a cliff-forming welded rhyolite tuff.

Erosion and sedimentation in northwestern New Mexico

D. E. Burkham, reporting on the results of a 10-year study of the hydrology of Cornfield Wash, in northwestern New Mexico, has discovered an apparent change in the precipitation and runoff pattern for that part of New Mexico beginning in 1955. Prior to that time, most of the precipitation occurred as torrential downpours from thunderstorms of small areal extent. Since 1955 most of the precipitation has occurred as small showers or from frontal storms of large areal extent with low precipitation intensity.

The lowered intensity of precipitation after 1955 has changed the runoff pattern, and hence the erosion effects. The reduction in the ratio of seasonal runoff to precipitation, after 1955, amounts to approximately 55 percent. Analysis of long-term precipitation and runoff records suggests that a significant change in the ratio of seasonal runoff to rainfall occurs at intervals of about 10 years.

Faulting and its relation to ground water in the Flagstaff area, Arizona

During an investigation for additional water supplies for the city of Flagstaff, Ariz., J. P. Akers (Art. 39) found that wells tapping fractured rocks of the Coconino Sandstone in the vicinity of major faults yield 10 to 50 times as much water as those tapping similar rocks that are unfractured. Aquifer tests at the sites of four municipal (Flagstaff) wells indicate that transmissibility, hence fracturing, increases toward the fault zones. Transmissibility determined at the 4 sites ranged from 5,000 to 50,000 gpd per foot, whereas away from fault zones transmissibility generally is less than 1,000 gpd per foot. Similarly, the specific capacity of the 4 city wells ranged from 2.5 to 8.6 gpm per foot of drawdown, whereas the specific capacity of nearly all wells in the area tapping unfractured Coconino Sandstone is less than 1 gpm per foot of drawdown.

BASIN AND RANGE REGION

Geologic and geophysical investigations during fiscal 1962 have been concentrated in central and eastern Nevada, western Utah, southeastern Arizona, and the Death Valley–Mojave Desert area of California, and some of the significant results are given below. Results of hydrologic investigations recently completed or in progress in these same States are also presented. Results of additional studies are summarized on other pages as follows: mineral deposits in sections beginning on pages A1 and A5; floods, page A99; paleontology, page A75; geomorpholgy, page A76; major crustal studies, page A84; evapotranspiration studies, pages A101 and A103; potassium-argon age determinations, page A94; geological and hydrologic work at the Nevada Test Site on page A105 and in the section beginning on page A106; ground water at the Nevada Test Site, page A110; and radioactive-waste disposal, page A115.

Structural geology—Arizona

In the Klondyke quadrangle, F. S. Simons and D. B. Brooks have mapped the Grand Reef fault, a large normal fault, extending along the west side of the Turnbull–Santa Teresa Mountains block but not delimiting that block. Volcanic rocks of Late Cretaceous or early Tertiary age west of the fault are dropped down against rocks ranging in age from early Precambrian to Pennsylvanian; the stratigraphic throw appears to be at least 1,300 feet.

Structural geology and geophysical studies—Nevada

Mapping in the southern part of Esmeralda County, by J. P. Albers, J. H. Stewart, and E. H. McKee has revealed a prominent easterly structural trend marked by elongate bodies of granitic rock, by folds associated with these intrusive bodies, and by high-angle faults. The largest eastward-trending fault passes just north of the village of Gold Point and has a stratigraphic separation of at least 6,000 feet.

Also from fieldwork by Albers and Stewart, in addition to studies by H. C. Cornwall in Nye County, evidence is growing that a strike-slip fault, originally recognized by H. G. Ferguson and S. W. Muller, extends for about 150 miles from Soda Springs Valley southeastward across Clayton Valley, under Sarcobatus Flat, and along the southwest margin of Bare Mountain. The fault is believed to have a right-lateral slip of the order of 4 to 10 miles and to represent one of at least 3 subparallel structures that constitute major elements of the Walker Lane.

Further study by C. R. Longwell during late 1961 of structural features adjacent to the Arrowhead fault in the Muddy Mountain area rules out a previously favored concept that movement on that fault had an important strike-slip component. Results of the recent study confirm that the Muddy Mountain thrust is present north of the Arrowhead fault, though it is concealed there beneath the downthrown block of the faulted thrust plate (Art. 144).

G. A. Thompson and D. E. White report that in the Basin and Range province near and south of Reno the ranges were formed by a combination of warping and block faulting, starting in Pliocene time. Extensive volcanism was concentrated largely in the ranges, and uplift and volcanism may be genetically related.

R. E. Wallace and N. J. Silberling have determined that the complex structure in the Antelope Springs or Pershing area at the southern end of the Humboldt Range is a large fan fold at least 5 miles across and 6 miles long and having flanks overturned both northeast and southwest. The structure involves beds of lower Jurassic age and is cut by diorite of possible Late Jurassic or Early Cretaceous age.

Harold Masursky has recognized that the areal distribution of Tertiary rocks in the Cortez and Shoshone Ranges of central Nevada indicates a shift in the high-angle or basin-range fault pattern from east-west in Oligocene time, to N. 20° W. in Miocene and Pliocene time, to north-south and N. 50° E. in Pliocene and Pleistocene time.

From his work in the Schell Creek Range, Harald Drewes believes that part of the complexity of the thrust faults in eastern Nevada is a result of overlapping of several types of faults: huge slumps, low-angle normal faults, bedding-plane thrust faults, and, locally, high-angle normal faults. The apparently conflicting interpretations of direction, age, and genesis of movement show promise of resolution with careful separation of these structural types. Article 1 discusses the stratigraphic and structural controls in the Taylor mining district in the Schell Creek Range.

Geologic mapping by A. L. Brokaw in the Egan Range south of Ely reveals that the structure of Ward Mountain consists of a pair of major folds, trending northwest and overturned to the east. The fold belt is truncated at both ends by faults. The structural pattern suggests a relation to large-scale thrust faulting, but faults of this type have not yet been recognized within this block. Northwest and west of Ward Mountain, however, Mississippian to Permian rocks are thrust over rocks of Devonian to Permian age, and north of Water Canyon slicing along thrust faults has removed about 1,500 feet of the lower part of the Guilmette Formation.

The East Range fault, Humboldt and Pershing Counties, Nev., extends at least 2 miles farther northward than previously mapped, according to Philip Cohen, (Art. 4). Evidence for the extension of the fault includes alined springs, a localized ground-water mound, highly mineralized thermal water, hydrothermal alteration of alluvium and consolidated rocks, and a buried bedrock high.

Offsets of extensive aeromagnetic and gravity anomalies are being used by D. R. Mabey to infer the amount and direction of lateral movement along some major faults and fault zones in the Basin and Range province. Lateral displacement of 3 miles along a fault in central Nevada has been inferred on the basis of magnetic anomalies. An apparent offset of gravity anomalies is consistent with the postulated 40-mile displacement along the Garlock fault based on geologic evidence.

A regional Bouguer-anomaly map of Nevada was compiled at a scale of 1:500,000 using U.S. Geological Survey data. The map has a 10-milligal contour interval and will be used as part of the gravity map of the United States now in preparation. Parts of the map are generalized from larger scale maps prepared by M. F. Kane, D. L. Healey and D. R. Mabey. The larger local anomalies are produced by the density contrast between the sedimentary and volcanic rocks of Cenozoic age and the more dense older rocks. The more extensive anomalies are related to regional topography.

Structural geology—Utah and Idaho

W. J. Carr and D. E. Trimble have recognized an east-dipping thrust zone in the American Falls–Pocatello area of Idaho that they believe may extend southward to join the Willard thrust of northern Utah. This thrust zone is the western margin of a belt of older rocks bounded on the east by the Bannock thrust zone.

The Oquirrh Formation in the northern Oquirrh Mountains, Utah, differs markedly from the section of equivalent age span in the central and southern parts of the range, according to E. W. Tooker and R. J. Roberts. The sections are separated by the North Oquirrh thrust. North of the thrust the Oquirrh Formation aggregates about 10,100 feet in thickness and has been divided into 6 units ranging in age from possible Late Mississippian to Early Permian, although no fossils of Late Pennsylvanian age have been recognized. In contrast, the stratigraphic section south of the thrust contains faunas representative of all the stages in the Pennsylvanian and Early Permian, and is more than 24,000 feet thick.

A map of the Boulter Peak quadrangle, Utah, by A. E. Disbrow (1961) shows that a right-lateral strike-slip fault trending northeast offsets the axis of the north Tintic anticline at least 4,000 feet.

Stratigraphy—Arizona

Mapping by P. M. Blacet in the Mt. Union quadrangle revealed a foliated quartz diorite unconformably below the Texas Gulch Formation of the Yavapai Series. This is the first known occurrence of a plutonic rock older than the Yavapai Series and calls for a reappraisal of the early Precambrian history of the Southwest.

A. F. Shride and Madora Krieger have concluded that the Cambrian rocks in the region between the Holy Joe Peak quadrangle and the Globe-Superior area consist of the lower units of the Abrigo Formation and locally of the underlying Bolsa Quartzite.

In the Whetstone Mountains, S. C. Creasey has recognized about 25 feet of relief on the surface of the unconformity separating the Abrigo Formation and the Martin Limestone, in decided contrast to the unusual stability displayed during this part of geologic time in the Dragoon Mountains 20 miles to the east.

In the southeastern part of the Canelo Hills in southeastern Arizona, several lenses of upper Paleozoic sedimentary rocks crop out in a terrane of silicic volcanic rocks of probably Tertiary age. These lenses are believed by F. S. Simons to be slabs that were transported on or within flows of silicic lava. The lenses consist mainly of carbonate rocks with subordinate quartzite and are up to 1,300 feet in greatest dimension.

In mapping the Superior quadrangle, D. W. Peterson has divided rocks previously considered to be "Cambrian Troy Quartzite" into Precambrian Troy Quartzite and quartzites of Cambrian age in accord with the concepts of M. H. Krieger.

J. R. Cooper has shown that the volcanic pile of the Sierrita Mountains was formed at essentially the same time as the volcanic pile of the Cerro Colorado but was derived from a different center of eruption.

Stratigraphy—Nevada and California

Precambrian and Cambrian rocks of Esmeralda County, Nev., at least 13,000 feet thick and lying in a structurally conformable sequence, have been described by J. P. Albers and J. H. Stewart (Art. 126). At least 3,600 feet of the sequence is of Precambrian age, 7,500 feet is of Early Cambrian age, and 1,900 feet is of Middle and Late Cambrian age.

Fieldwork by A. R. Palmer and J. H. Stewart in southern Nevada and southeastern California shows that the Zabriskie Quartzite of Hazzard [37] is a regionally distributed formational unit varying strikingly in thickness from less than 100 feet in the Nopah Range, Calif., and Spring Mountains, Nev., to about 1,000 feet at Bare Mountain, Nev. Farther northwest in southern Esmeralda County, beds possibly representing the Zabriskie are less than 100 feet thick, and the formation is not recognizable in the central part of the county. Beds previously reported [38] to be the trilobite-bearing Johnnie Formation are now believed by Palmer and Stewart to belong to the Wood Canyon Formation.

R. J. Ross, Jr., has made studies of laterally changing Ordovician faunas just below the Eureka Quartzite across southern Nevada. On the east, the unfossiliferous Eureka Quartzite rests on the *Anomalorthis* zone (Whiterock Stage), whereas to the west presumably younger faunal elements of the Marmor and Ashby Stages occupy this interval. Either the strata immediately under the Eureka become progressively younger toward the west, or the observed faunal differences are partly a function of lateral facies change rather than one of age.

Research on Great Basin fusulinid Foraminifera by R. C. Douglass has been concentrated on rocks on Pennsylvanian age. A preliminary study of fusulinids from the Egan Range, Nev., indicates possible occurrence of Late Pennsylvanian strata in the Ely Limestone east of Lund. Species of *Triticites* found below the chert-pebble conglomerate at the base of the Riepe Spring Limestone [39] seemingly bridge the reported unconformity between Middle Pennsylvanian and Permian.

Geologic mapping by D. H. Whitebread shows that the Pioche Shale is exposed for a strike length of about 10 miles in the northern half of the Garrison quadrangle, Nevada. The "Wheeler Limestone" unit of the Pioche, which is the host rock for beryllium minerals in the Mount Wheeler mine, averages 8 to 12 feet in thickness in this area.

Comparison by Harold Masursky of the Upper Ordovician, Silurian, and Devonian carbonate rocks in the Cortez and Horse Creek Valley quadrangles, Nevada, with the standard section at Eureka, Nev., indicates a change from 75 percent dolomite at Eureka to less than 5 percent dolomite at Cortez. This facies change indicates that the 200-mile-wide zone of shelf dolomites of eastern Nevada gives way to deeper water limestones within 30 miles.

N. J. Silberling in collaboration with D. B. Tatlock has discovered new fossil occurrences in western Persh-

[37] Hazzard, J. C., 1937, Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Jour. Mines and Geology, v. 33, no. 4, p. 273–339.

[38] U.S. Geol. Survey, 1960, Synopsis of geologic results: U.S. Geol. Survey Prof. Paper 400–A, p. A40.

[39] Steel, Grant, 1960, Pennsylvanian-Permian stratigraphy of east-central Nevada and adjacent Utah: Intermountain Assoc. Petroleum Geologists Guidebook, 11th Ann. Field Conf., p. 93 (chart 1), p. 102.

ing County, Nev., that indicate an early Mesozoic age for previously undated metasedimentary rocks sporadically distributed over an area of 2,500 square miles. Tatlock also has tentatively correlated a metavolcanic sequence at the north end of the Selenite Range with similar rocks at Black Rock known to be of late Early Permian age.

Near Winnemucca, Nev., five lithologic units of Lake Lahontan age are recognized by Philip Cohen (Art. 81) in the Humboldt River valley—the lower silt and clay, alluvium, the medial gravel, the upper silt and clay, and gravel-bar deposits. The lower silt and clay unit was deposited in an early deep-lake stage. The alluvium and the medial gravel units were deposited largely by streams during a period of desiccation, and the upper silt and clay and gravel-bar units were deposited during a second and final deep-lake stage.

Recent stratigraphic studies by N. J. Silberling in the Humboldt Range, Nev., demonstrate marked lateral variation in the composition of the Star Peak Group, which includes the Prida and Natchez Pass Formations of Middle and early Late Triassic age. The upper part of the Prida Formation thickens from south to north at the expense of the overlying Natchez Pass Formation. During latest Middle and earliest Late Triassic time, when shallow-water carbonate rock was being deposited at the site of the southern Humboldt Range, deeper water limestone was still accumulating to the north. This and other stratigraphic evidence augments the paleogeographic interpretation of shoreward deposition toward the southeast and offshore deposition toward the northwest during Middle and Late Triassic time in northwestern Nevada.

Continued mapping, fossil collecting, and paleontologic study by C. W. Merriam indicate that the problematic vanadium-bearing shales and sandstones of the Cockalorum Wash quadrangle, Nevada, are of Devonian age and, in part, possibly Early Mississippian. These vanadium-bearing rocks are in fault contact with Middle and Late Devonian dolomite and limestone of the Nevada and Devils Gate Formations.

Geologic mapping in the Carlin quadrangle, Nevada, by J. F. Smith, Jr., and K. B. Ketner, disclosed a shale facies of Late Mississippian age that contains well-preserved ostracodes. Preliminary study of the ostracodes by I. G. Sohn indicates that the lower part of this section is of Meramec equivalent and the upper part is of Chester equivalent.

Geologic mapping in the Pancake Range, northern Nye County, Nev., by F. J. Kleinhampl has revealed that the Pilot Shale of Devonian and Mississippian age extends into the central part of the range. There the Pilot appears to be represented by only about 5 to 15 feet of calcareous to siliceous shale and siltstone, considerably less than that reported in the northern part of the Pancake and Grant Ranges or in the Eureka and Hamilton mining districts.

J. H. Stewart (Art. 79) finds that in areas in the southern Diamond Mountains and in the northern Pancake Range, White Pine County, Nev., the Chainman and Diamond Peak Formations consist of several thousand feet of siltstone and minor amounts of sandstone, conglomerate and silty limestone, divisible into several major lithologic units. Thick pale-yellowish-brown sandstone beds are a distinctive part of the formation in the areas studied.

Examination by C. R. Longwell of the sedimentary section exposed in Frenchman Mountain, Las Vegas and Henderson quadrangles, Nevada, confirms the conclusion that no identifiable rocks of Ordovician age are in that structural block. Only 6 miles to the north, across the course of the Las Vegas shear zone, an exposed but incomplete section dated as Ordovician represents the Pogonip Group, the Eureka Quartzite, and the Ely Spring Dolomite.

Discovery by D. C. Ross of Lower Ordovician graptolites (identified by R. J. Ross, Jr) in the Independence quadrangle, California, marks the first recognition of Lower Ordovician strata in the Inyo Mountains, and helps to bridge a gap previously believed unfossiliferous in the geologic column of the Inyo Mountains.

Geologic mapping in the Blanco Mountain quadrangle, California, by C. A. Nelson has resulted in recognition of rocks of the Middle and Upper Cambrian Emigrant Formation in this part of the Inyo Mountains.

Stratigraphy and structural geology—New Mexico

Studies by G. O. Bachman show that Pennsylvanian rocks that are probably equivalent to rocks of Missouri age in the midcontinent region (zone of *Triticites ohioensis* and *T. irregularis*) may attain a total thickness of more than 600 feet in local areas in the extreme southern part of the Oscura Mountains. This is unusually thick for rocks of this age in southern New Mexico—with the exception of the Sacramento Mountains, where similar thicknesses have been reported by other workers.

At the southern end of the San Andres Mountains, Bachman also has discovered high-angle east-trending reverse faults which may have broken through the surface locally and shed landslide blocks.

Igneous rocks—Mojave Desert

Geologic mapping of the Ord Mountains in the south-central part of the Mojave Desert region in California by T. W. Diblee, Jr., has revealed quartz monzonite of Mesozoic age that has intruded gneiss of Precambrian(?) age and associated hornblendite. Andesitic or latitic porphyry dikes of Mesozoic age intruded this complex; and on East Ord Mountain rocks of andesitic or latitic composition, including breccia and devitrified obsidian, appear to form a large plug.

Cenozoic rocks and history

Reconnaissance mapping by G. W. Walker and C. A. Repenning in Lake and Harney Counties, Oreg., as well as preliminary study of fossil vertebrates from several new localities, has established a Miocene and older age for volcanic and tuffaceous sedimentary rocks exposed in Steens Mountain and the Pueblo Mountains. In recent years, these rocks have been considered Pliocene in age. Also, several fossil mammals new to the Miocene of Oregon were found.

Interpretation by W. T. Kinoshita and W. E. Davis of gravity data across the valley west of Lakeview, Oreg., indicates that the basin fill is about 9,000 feet thick in the eastern part of the valley, and that a hidden north-trending fault zone lies along the east side.

Preliminary study by D. M. Lemmon of hydrothermal alteration of Tertiary volcanic rocks south of Squaw Pass in the Frisco quadrangle, San Francisco district, Utah, indicates that the principal products in the areas studied are quartz and kaolinite; alunite is present in the bleached areas about White Mountain, and cristobalite occurs southwest of White Mountain.

Anomalous Foraminifera in Cenozoic strata of the Mojave and Colorado Deserts have been investigated by Patsy Smith. Outcrop and well samples from localities along the Colorado River and adjacent dry lakes reveal the presence of Foraminifera characteristic of lagoonal or estuarine environments. Some of these fine-grained foram-bearing sediments have been traced laterally into subaerial fanglomerates.

Study of glaciation features in Little Cottonwood and Bells Canyons, Utah, by G. M. Richmond suggests that the west front of the Wasatch Mountains was uplifted more than 6,000 feet relative to the adjacent Great Salt Lake basin in Pleistocene time. Deposits of 2 middle Pleistocene glaciations were recognized and moraines of 2 late Pleistocene glaciations are present in the canyons. Outwash deposits of the two sets of moraines (early and late stages of Bull Lake Glaciation) at the mouths of Little Cottonwood and Bells Canyons intertongue with and are overlapped by deposits of the two high stands of Lake Bonneville (Alpine and Bonneville Formations).

A. L. Brokaw reports that the distribution of Tertiary sedimentary rocks in the Ely quadrangle, Nevada, indicates that the Sheep Pass (Eocene) basin of deposition may have been more extensive than shown by other workers in the area. Scattered patches of rocks, lithologically and faunally similar to the Sheep Pass Formation of Winfrey,[40] have been mapped on both sides of the range and within the range. The distribution of these patches suggests that before faulting and subsequent erosion the beds covered the area now occupied by the mountain mass.

In the Holy Joe Peak quadrangle, Arizona, Madora Krieger has divided the rocks of Miocene(?) to Pleistocene(?) age into 14 units including basaltic or andesitic flows; silicic ash flows composed of welded and nonwelded tuffs; rhyolitic flows, tuffs, and plugs; and interbedded sedimentary rocks.

Study of the Cenozoic history of the Duncan-Clifton and Gila-San Simon Basins, Ariz., by R. B. Morrison has shown that in pre-Gila River time there was a long relatively arid interval followed by a shorter wet interval, probably coeval with a major Pleistocene glaciation, when lakes rose several hundred feet in each basin. The lakes probably overflowed the basin divides and initiated this portion of the Gila River at this time.

E. S. Davidson reports that basin parameters in the Safford Basin, Ariz., were formed by erosion preceding and contemporaneous with block faulting and that both erosion and faulting were major contributors to basin development. Post-block-faulting drainage in the Safford Basin was largely interior from late Tertiary or early Pleistocene to middle Pleistocene time and resulted in deep accumulations of sediment in the basin. Lithofacies mapping of these sediments shows that gravels deposited on alluvial fans should not be expected to coalesce along entire mountain fronts, as formerly thought. Regional uplift, tilting, and accompanying minor faulting began province-wide erosion and development of through drainage which persists to this day.

In the Cibola area of southwestern Arizona, D. G. Metzger has found that degradation by a through-flowing stream—probably the Colorado—during Pliocene(?) time dissected earlier basin deposits. Aggradation by the Colorado River during the early Pleistocene, or perhaps starting in the Pliocene, resulted in an accumulation of deposits to at least 900 feet above the present sea level. Later in the Pleistocene, degradation by the Colorado River removed much of the material. Smaller scale degradation and aggradation along the flood plain resulted in the present flood-plain topography.

A series of climate-controlled late Quaternary lakes in Searles Valley, Calif., dried up to form layers of economically recoverable salines. Mapping by G. I. Smith (Art. 82) of the laterally equivalent sediments

[40] Winfrey, W. M., Jr., 1958, Stratigraphy, correlation, and oil potential of the Sheep Pass Formation, east-central Nevada: Am. Assoc. Petroleum Geologists Rocky Mtn. Sec. Geol. Record, 8th Ann. Meeting, p. 77–82.

exposed around the edges of the valley indicate several fluctuations of the larger lakes that are not evident in the subsurface record. The distribution of exposed deposits supports the inference that the lake has not overflowed the basin since early Wisconsin time.

In the Imperial Valley of southeastern California, J. H. Robison has found geomorphic evidence of shorelines of possible marine origin at 140 to 160 feet above sea level. The body of water associated with these shorelines would antedate Lake Cahuilla, of probable late Pleistocene to Recent age, whose shorelines lie 30 to 40 feet above sea level.

Hydrogeology of basins

Hydrologic studies in the Las Vegas, Nev., ground-water basin recently completed by G. T. Malmberg (1961) indicate about 38,000 acre-feet of recharge to the ground-water reservoir from all sources in 1961. The estimated ground-water discharge from wells in 1961 was about 45,000 acre-feet and evapotranspiration losses from ground water were about 23,000 acre-feet for a total of about 68,000 acre-feet, or almost twice the rate of replenishment to the ground-water reservoir. Withdrawals have lowered water levels as much as 100 feet, and the decline in head has resulted in a cessation of flow from most artesian wells and springs. Reduction of artesian pressure due to withdrawal of artesian water has resulted in some land subsidence.

Investigations by R. L. Mower show that artesian heads in Pavant Valley, Millard County, Utah, declined 3 to 35 feet during the period 1950–60, owing to increased use of ground water for irrigation and below-normal precipitation. In 1960 about 67,000 acre-feet of ground water was discharged through wells. The largest withdrawal was in the Flowell area, where a large cone of depression has formed in the piezometric surface. Smaller cones of depression have formed in the McCornic, Greenwood, and Kanosh areas, where withdrawals of ground water are smaller. The piezometric surface and water table declined about 3 to 5 feet in the areas between the cones of depression owing to below-normal precipitation.

On the basis of ground-water studies in Grant County, N. Mex., F. D. Trauger reports that the Gila Conglomerate of Quaternary and Tertiary age, bolson fill of Quaternary age, and stream-valley alluvium of Recent age furnish the principal ground water for domestic, stock, municipal supply, industrial supply, and irrigation use in the county.

The sequence of rocks commonly referred to as the Gila Conglomerate in Grant County can be divided into three members. These members can be distinguished locally in outcrops and in well cuttings, but they cannot be easily mapped at the land surface over any appreciable distance. The lower member in general is firmly consolidated and locally is much deformed; the middle member is poorly consolidated and in general is only slightly deformed; and the upper member is unconsolidated and undeformed. The thickness of the lower and middle members is measured in hundreds and perhaps thousands, of feet, whereas the upper member generally is only tens of feet thick.

Ground water in pre-Tertiary rocks

S. L. Schoff and I. J. Winograd (1961, 1962, and Art. 105) concluded from a study of records of core holes at the Nevada Test Site that the carbonate rocks of Paleozoic age are not necessarily barriers to the movement of ground water, as previously had been implied. Rather, fractures in these rocks, where saturated, may be capable of yielding substantial quantities of water to wells finished in them.

The Madera Limestone of the Magdalena Group of Pennsylvania age, which is the only important aquifer in the Manzano Mountains, N. Mex., has a maximum yield of a few tens of gallons per minute, according to studies by F. B. Titus, Jr. Numerous dry holes have been drilled into the Madera in the eastern part of the Manzano Mountains. Data are being collected that will allow outlining the area in which production from the Madera is not reliable. In the Sandia Mountains the Madera is important as an aquifer only in the northern and extreme southeastern parts. Elsewhere in the Sandias the following formations all yield water locally to wells: the Abo Formation, Glorieta Sandstone, and San Andres Limestone of Permian age; the Santa Rosa Sandstone and Chinle Formation of Triassic age; the Entrada Sandstone and Morrison Formation of Jurassic age; and the Dakota Sandstone, Mancos Shale, and Mesaverde Formation of Cretaceous age.

Interbasin movement of ground water

G. W. Sandberg reports that recent investigations of ground water in five basins of southwestern Utah indicate that the basins are connected hydraulically even though each is separated geologically. Water-level contours of a composite area made up of the five basins and connecting areas indicate that ground water moves from the high basins—Parowan Valley, the Beryl-Enterprise district, Cedar City Valey, and Beaver Valley—thence converging on the basin of lowest altitude, the Milford district, which is located north and west of the others. Water-level contours also indicate that some water is moving out of the lowest basin. Water levels are declining appreciably only where there is considerable pumping. Unpumped areas cover nearly as much land as do pumped areas and represent sites of possible new development.

I. J. Winograd (1962a, b, and Art. 104) has shown that ground water in alluvium and tuff beneath Yucca Flat, Nev., is semiperched above thick, nearly impermeable, zeolitized tuff. The water moves away first by drainage downward through the tuff into underlying carbonate rocks. Presumably it then moves laterally out of the Yucca Flat area through the carbonate rocks.

Hydrogeochemistry

A. M. Diaz reports that investigations in the Great Salt Lake basin establish that during the 1960 water year, almost 2 million tons of salt was contributed to Great Salt Lake by streams, springs, and drains carrying industrial and municipal waste. Although the runoff in the basin was below normal for 1960, the present findings are about twice the magnitude of estimates of past hydrologic investigations.

Philip Cohen (Art. 114) reports that bleached rocks are the source of practically all of the sulfate in most of the ground water of the Truckee Meadows area in the vicinity of Reno, Nev. The sulfate content of the water of the area tends to decrease with increasing distance from the areas of bleached rock.

Studies in Tooele Valley, Utah, by J. S. Gates show that a well-defined 1- to 5-mile-wide tongue of ground water of relatively low mineral content extends from the southwest corner of the valley to about 3 miles from Great Salt Lake. A similar but less well-defined tongue of ground water extends from the southeast corner of the valley to within about 2 miles of the lake. These tongues of ground water are bounded by water of greater mineral content and probably occur in permeable stream-channel deposits. It has also been discovered (Art. 142) that a northwest-trending fault divides the Erda ground-water district of northeastern Tooele Valley into hydraulically separate areas.

Estimating porosity from specific gravity

Cohen (Art. 15) reports that the porosity of samples of the flood-plain deposits of the Humboldt River valley near Winnemucca, Nev., can be estimated from the dry unit weight of the samples within about ±1.5 percent if the average absolute specific gravity of the samples is known. The relation between these parameters may prove useful in future studies for estimating porosity.

COLUMBIA PLATEAU AND SNAKE RIVER PLAINS REGION

Structural and stratigraphic studies continue in the John Day area of Oregon and the Snake River Plains of southern Idaho. Considerable progress has been made in the continuing studies of the availability and quality of ground water in parts of Washington, Idaho, and Oregon. Results of other studies in this area are reported elsewhere in this chapter as follows: uranium deposits, page A9; paleontology, page A75; gravity studies, page A85; and radioactive waste disposal, page A114.

Gravity studies in Oregon and Idaho

A study by W. T. Kinoshita of gravity data in Bear Valley north of Seneca, Oreg., suggests that the valley is bounded by faults of an east-trending graben about 4,000 feet deep.

A reconnaissance geologic map of the west-central Snake River Plain, Idaho, recently completed by H. E. Malde, C. H. Marshall, and H. A. Powers, shows a close relation between geologic structure and the gravity distribution as reported by D. P. Hill and others (1961). The principal structural feature is a northwest-trending graben about 30 miles broad, bounded on the north and south by volcanic highlands of early Pliocene age. Within this structural depression, the contours that outline several elongated areas of high gravity are nearly parallel to faults that give shape to the mountain fronts. One gravity high southwest of the Bruneau Valley matches a niche defined by the faulted outline of the lower Pliocene volcanic rocks, although the surface rocks in the niche are low gravity sedimentary rocks of middle Pliocene age. These relations seem to demonstrate that the gravity highs and the graben were formed simultaneously, mainly before middle Pliocene time. The regional geology suggests that the concealed heavy rocks causing the gravity hights are more plausibly explained as fissure fillings by material injected from the mantle rather than as down-faulted lava flows.

Structural and stratigraphic studies in Oregon and Idaho

Late Cenozoic normal faults in western Idaho and northeastern Oregon are controlled by the character of pre-Mesozoic rock complexes, according to a study by W. B. Hamilton. The massive Idaho batholith is little deformed, whereas its western border zone of schist and gneiss is broken by many normal faults that are mostly semiconcordant to the general northerly strike and eastward dip of the older rocks. West of this belt is the Columbia Plateau province of irregular anticlinal uplifts and northwest-trending normal faults that are superimposed across a complex of east- to northeast-trending relatively incompetent low-grade metamorphic rocks intruded by small plutons of Late Jurassic(?) age.

Detailed mapping by T. P. Thayer and C. E. Brown showed that Ironside Mountain, 45 miles east of John Day, Oreg., is a 3- by 6-mile fault block of complexly folded basaltic to rhyolitic lavas of Lower Tertiary age dropped down into impermeable foliated sedimentary and metavolcanic rocks of Jurassic and Triassic age. The block of Tertiary lavas constitutes a potentially important ground water reservoir. The Ironside Mountain boundary fault is believed to be pre-middle Miocene in age, and unrelated to Pliocene and Pleistocene faulting that raised a larger structural mass of which Ironside Mountain is a part.

A reconnaissance field and petrologic study of the large Island Park caldera in the northeastern Snake River Plain was made by W. B. Hamilton. A circular mass 18 miles in diameter was dropped during late Pleistocene time from the center of a shield volcano of rhyolite tuff, and the collapsed area was flooded by intercalated rhyolite and basalt erupted from vents interspersed within the caldera. The eruptive pattern and sequence show that basalt and rhyolite magmas were present simultaneously within the large magma chamber beneath the caldera.

According to I. G. Sohn, the abundant silicified ostracodes in the Permian Coyote Butte Formation of eastern Oregon belong to species of Leonard age.

Volcanic ash in local surficial and terrace deposits in the John Day area of Oregon is attributed by Ray Wilcox and Howard Powers to the great Mazama eruption of Crater Lake, generally regarded on the basis of radiocarbon dating as having occurred about 6,500 years ago. These particular Recent ash deposits in the John Day region match the known Mazama material of the Crater Lake area in chemical, spectrographic, and optical properties of the glass as well as in optical properties of phenocrysts. The Mazama material has been compared with material of other Recent source vents in the Pacific Northwest and found to differ sufficiently to enable its recognition even at distant localities in Washington, Idaho, Montana, and Nevada, where locally it provides a convenient marker horizon for dating geomorphic and archeological events.

Ground water in basalts of Washington and Idaho

At least six stratigraphically distinct units have been distinguished in the Yakima Basalt of central Washington by M. T. Grolier and J. W. Bingham. The major aquifers in the area are permeable zones at and adjacent to the contacts between these units.

Rapid expansion of ground-water use for irrigation in eastern Idaho during the past decade has caused a water-level decline of 1 to 15 feet in the basalt aquifer of the Snake River Plain. M. J. Mundorff estimates that in 1961, an area of about 720,000 acres was irrigated with about 2,300,000 acre-feet of ground water. Natural discharge from the aquifer has declined only slightly because of the very large volume of water in storage and the distance from pumped areas to discharge areas.

Information collected by E. G. Crosthwaite in the Artesian City area east of Twin Falls, Idaho, shows that water levels have declined 5 to 100 feet during the past 7 years (1954 to 1961) because of pumping ground water to irrigate about 25,000 acres. Water levels have declined moderately in basalt; the largest declines have been in aquifers in silicic volcanic rocks.

The basalt in central Twin Falls County, Idaho, yields much smaller quantities of ground water to irrigation wells than the basalt in the main part of the Snake River Plain. E. G. Crosthwaite concludes that only a limited amount of a sizable arable acreage can be irrigated with contiguous ground water, and that water from other sources or areas will have to be imported for extensive agricultural development.

Birch Creek, in a basin tributary to the Snake River Plain along its north flank, is a stream with a remarkably uniform discharge that rises from a group of springs behind a hydrologic barrier about midway between the head and mouth of the basin. Studies by M. J. Mundorff indicate a large storage capacity in the aquifer. Pumping from storage behind the barrier would reduce natural outflow to some extent, but the total amount of water available during the irrigation season could be increased twofold or threefold by this means.

Results of studies of the hydrology of radioactive-waste disposal at the National Reactor Testing Station, Idaho, by P. H. Jones show that the local direction of ground-water flow is more closely related to the geometry (thickness and areal continuity) of the aquifer system in the Snake River Group than to the regional hydraulic gradient.

P. R. Stevens reports that ground water is the chief source of water for irrigation of more than 60,000 acres in the Mud Lake basin in the northeastern part of the Snake River Plain. The annual withdrawal from 200 wells exceeds 300,000 acre-feet annually. The average yield of wells is about 4,500 gpm, and specific capacities average about 1,500 gpm per foot of drawdown. Pumping has caused a net decline in the water level of 5 or 6 tenths of a foot a year since 1955.

That large amounts of ground water can be obtained from gravel and basalt aquifers underlying the eastern end of the Snake River Plain from St. Anthony southwestward to the Snake River is shown by an investigation in that area by M. J. Mundorff. Withdrawals from the regional aquifer probably will not affect water levels in overlying perched aquifers, and hence will not interfere with return flow to Henrys Fork and Snake River. Large withdrawals, however, would eventually reduce inflow to American Falls Reservoir, 60 to 70 miles downgradient, where the regional aquifer discharges nearly 2 million acre-feet of water annually.

PACIFIC COAST REGION

Some of the recent findings of geologic, geophysical, and hydrologic investigations in parts of California, Oregon, and Washington are summarized below. Additional information of a more topical nature is presented on other pages as follows: mineral deposits, page A2; oil and coal, page A10; water resources, Tacoma, Wash., page A12; paleontology, page A74; geomorphology, page A77; glaciers and glacial hydrology, page A78; glacial geology, page A79; major crustal studies, page A84; potassium-argon age determinations, page A94; aquifer compaction, page A102; engineering geology, page A104; and subsidence, page A105.

Geologic studies in Washington

Stratigraphic studies southeast of Seattle by J. D. Vine and H. D. Gower indicate that nearly 6,000 feet of coal-bearing strata in the Eocene Puget Group south of the Cedar River correlate with 14,000 feet of strata north of the river, which contain abundant clastic volcanic material. This northern sequence includes a wedge of marine rocks, as much as 3,000 feet thick, at the base of the exposed section. The volcanic-rich northern facies was deposited in a rapidly subsiding trough whose southern margin is located near the present Cedar River.

D. F. Crowder and R. W. Tabor find that the imposing Glacier Peak volcanic cone in the northern Cascade Mountains consists of only 3,000 feet of Pliocene and Quaternary lavas; these cap a ridge of basement rocks that is 7,000 feet high. The youngest flows from the ancient volcano partially fill glacial valleys cut in older lavas and basement rocks.

In central Pierce County geologic mapping and examination of well logs by K. L. Walters and G. E. Kimmel have revealed that lacustrine and fluviatile Tertiary sediments that formerly were believed to be somewhat restricted in areal occurrence were found to be relatively extensive. Fossil plants collected from several localities were identified by J. A. Wolfe as being late-middle to late Miocene. The flora from one of the Pierce County localities is correlative with a flora found in the Wilkes Formation of the Toledo–Castle Rock area. A nonglacial unit has been found to occur between Vashon Drift and Salmon Springs Drift in the southern Puget Sound lowland. Radiocarbon dating suggests that this unit was deposited between 28,000 and 37,000 years ago.

Geologic and geophysical studies in Oregon

The geologic map of Oregon west of the 121st meridian (F. G. Wells and D. L. Peck, 1961) shows the interrelations of the thick marine Tertiary sequence of the Coast Range and the Tertiary and Quaternary continental volcanic rocks of the Cascade Range; to the south both marine and continental rocks overlap Mesozoic and Paleozoic metamorphic and plutonic rocks of the Klamath Mountains. The northeast structural grain of the rocks in the Klamath Mountains is reflected in the trend of folds and faults in Tertiary rocks in the western Cascade Range and in the Coast Range south of Tillamook; however, structures trend predominantly north to northwest in northwestern Oregon and east of the crest of the Cascade Range.

Interpretation by P. D. Snavely, Jr., of 40 chemical analyses of basalt from three Tertiary volcanic sequences of different age in the Coast Range indicates that these rocks are distinct chemically as well as petrographically. Basalt of the Siletz River Volcanic Series of early Eocene age contains less SiO_2 (average 48 percent on a water-free basis) and more MgO (average 6.7 percent) and CaO (average 11.4 percent) than younger basalts. The andesine basalt of the Nestucca Formation of late Eocene age contains more Al_2O_3 (average about 17 percent) than rocks of the other sequences. The middle Miocene tholeiitic basalt at Government Point is chemically and petrographically similar to the Yakima Basalt east of the Cascade Range. A plot of the analyses shows that the magmas of early and middle Miocene age evolved along the trend of the Hawaiian tholeiitic basalt series, but the older magma progressed much further in differentiation.

Aeromagnetic and gravity studies show pronounced magnetic anomalies and a broad gravity high near the Oregon coast between Waldport and Haceta Head (Bromery 1962). Although this anomalous area coincides in part with the areal outcrop of upper Eocene volcanic rocks, the total thickness of these flows ranges only from 1,500 to 2,000 feet and could not be responsible for the geophysical anomalies. The anomalous area possibly represents a structural high of rocks of the Siletz River Volcanic Series of early Eocene age, although this hypothesis is not supported by geologic evidence. Further analysis of gravity data indicates that the middle(?) to upper Eocene sedimentary and volcanic rocks and Oligocene strata attain a thickness of approximately 10,000 feet in the central part of the Nehalem River basin, and the post-Tillamook sequence is over 20,000 feet thick in the central part of the Tualatin Basin.

Geology of Klamath Mountains, Cascade Range, Coast Ranges, and coastal area of California

In the Condrey Mountain quadrangle, Siskiyou County, P. E. Hotz has mapped an eastward-dipping high-angle reverse fault that separates quartz-mica schist of the pre-Silurian Abrams Mica Schist from a younger sequence of amphibolite, quartzite, and marble. A few occurrences of cinnabar near the fault suggest that it guided the flow of mercury-bearing solutions and therefore warrants the attention of prospectors.

W. P. Irwin and P. W. Lipman (Art. 67) report that an extensive subhorizontal sheet of ultramafic rocks of Late Jurassic or older age in the eastern Klamath Mountains separates Paleozoic strata to the east from the underlying metamorphic Abrams and Salmon Formations. The regional discordance of the Paleozoic strata with the ultramafic rocks suggests that the sheet may have been intruded along a thrust fault or that the Paleozoic strata were later thrust over the sheet.

Geologic mapping by G. A. MacDonald north of Lassen Volcanic National Park, Calif., has revealed that andesite and rhyodacite lava flows of Pliocene(?) age, overlying the Tuscan Formation, were gently folded along nearly east-west axes and were faulted and eroded before deposition on them of a series of volcanic rocks ranging in composition from basalt to dacite. Eruptions of basalt, andesite, and dacite lavas recurred without any single definite sequence of types through Pleistocene and into historic time.

G. D. Bath finds that tabular masses of ultramafic rock are almost continuous along several major fault zones in the San Francisco Bay area. The extent of these partially buried masses is revealed by prominent anomalies mapped by an aeromagnetic survey. The anomalies indicate that thin ultramafic sheets extend almost continuously along the Hayward and Pilarcitos faults, and that serpentine along the shear zone crossing San Francisco extends at least 10 miles to the southeast beneath the sediments of the bay; however, only discontinuous masses occur along the San Andreas fault.

Investigations of Pacific Border province Silurian faunas by C. W. Merriam indicate close relationship of *Atrypella*-bearing faunas in the Klamath Mountains, Calf., to Silurian faunas of the southeast Alaska islands. These faunal affinities are consistent with close similarity of rock facies. In both regions the Pacific Border Silurian facies comprise graywackes, sandstones, thick conglomerates, pure limestones, and volcanic rocks. Unlike "stable shelf" Silurian carbonate rocks of the Great Basin, these Pacific Border geosynclinal Silurian strata include very little dolomite.

Patsy Smith has studied Foraminifera from a measured section through the Pliocene of the Los Angeles Basin. The forams represent shallow water at the top of the column and deeper water (to 4,000 feet) down lower in the column, and are very similar to Recent foram assemblages living off the California coast.

Geologic and geophysical studies in the Sierra Nevada

In the canyon of the North Fork of the American River, graywacke and slate of probable Silurian age are overlain with pronounced angular unconformity by strata of Mesozoic age (L. D. Clark and others, Art. 6). The older beds were complexly folded, regionally metamorphosed, and deeply eroded during late Paleozoic or Triassic time.

J. G. Moore and F. C. Dodge (Art. 7) describe the occurrence along the Kings River of marine fossils of Triassic or Jurassic age in a large metamorphic pendant in the Sierra Nevada batholith. The pendant, which is composed of metamorphosed arkosic sandstone, siltstone, and marble, is one of a group of similar metamorphic remnants that extends northward from Mineral King through the dominantly granitic terrane. These fossils, together with previously reported Upper Triassic fossils from near Mineral King, suggest that the strata of this group of pendants are all of Mesozoic rather than of Paleozoic age. This belt of pendants may extend at least 50 miles north of the Kings River. At Iron Lakes, near the southern boundary of Yosemite National Park, D. L. Peck and N. K. Huber find quartzite and marble interbedded with eastward-dipping metavolcanic rocks; farther east, across the trough of the Sierra Nevada synclinorium, Lower Jurassic fossils have been found in the metavolcanic rocks.

F. C. Calkins and D. L. Peck (1962) point out that the variety of sculpture of the walls of the Yosemite Valley resulted from the varied nature of the bedrock—principally the different degrees to which the various rocks are jointed. The more siliceous rocks are less jointed and therefore form the larger monoliths, such as El Capitan, Cathedral Rocks, and Half Dome. Broad talus slopes flank cliffs of the closely jointed, less siliceous rocks, such as the diorite of the Rock Slides.

Clyde Wahrhaftig (1962) concludes that the free-plunging falls in recesses in the walls of the Yosemite Valley were formed from cascades by the spalling of flat sheets along the cascades. The sheeting was apparently induced both by wetting and drying and by freezing and thawing.

Analysis by P. C. Bateman (1961b) of data gathered by W. D. Johnson in 1907 shows that the faulting near Lone Pine during the 1872 Owens Valley earthquake involved both dip-slip and right-lateral components of movement. This pattern of movement is opposed to the recent postulate of regional systematic left-lateral movement along the east side of the Sierra Nevada during the Cenozoic, but does not prove systematic right-lateral movement. The total amount of strike-slip movement since the Cretaceous is limited to a few miles by the correlation of two physically similar granitic plutons on adjacent sides of Owens Valley (D. C. Ross, Art. 145).

An analysis of releveling data obtained from the U.S. Coast and Geodetic Survey indicates that there has been a significant amount of internal deformation within the Sierra Nevada between surveys in 1940 and 1957. Changes in the elevation of bench marks west of Tenaya Lake are quite small and within the limits of probable error, but the eastern Sierra has been tilted upward to the east at an average rate of 0.1 μrad per year. This tilt rate is comparable to the current rate of isostatic rebound from glacial loading in Fennoscandia but is probably of tectonic origin. These data tend to confirm an earlier conclusion,[41] based on gravity observations, that the eastern half of the Sierra is slightly overcompensated.

Additional study of gravity and seismic measurements in the Sierra Valley, Calif., by W. H. Jackson suggests that this is an area of greater structural complexity than previously reported (Jackson and others, 1961). A prominent gravity minimum was found to conform to the general outline of the valley, with some major exceptions. Contrary to the northwest regional trend in this area, the anomaly has a northeast trend, which may represent a structural trend not yet detected at the surface. A chain of small gravity highs across the center of the valley is probably the expression of hills of pre-Tertiary rock and (or) dense Cenozoic volcanic rocks buried beneath lighter Cenozoic stream, transported sediments. These hills may form a partial "dam," which may affect the flow of ground water in Sierra Valley. The gravity field in parts of the Sierra Valley area suggests that the valley limit may be much greater than that shown by topographic expression.

Hydrologic studies in California

F. H. Olmsted and G. H. Davis (1961) have described the geologic features and ground-water storage capacity of the Sacramento Valley. Twenty geologic units have been identified, of which 9 yield little water and 11 yield water freely to wells. For 21 subareas, average-well discharge ranges from 250 to nearly 1,700 gpm; average specific capacity ranges from 21 to 106 gpm per foot of drawdown; and average well depth ranges from 120 to 494 feet.

The Sacramento Valley is in the northern part of a large structural trough, a downwarped basin of deposition filled with 20,000 feet of sedimentary materials, which range in age from Cretaceous to Recent. In general, the deposits contain fresh water to depths of 1,000 to 2,000 feet. The estimated total ground-water storage capacity of the zone, 20 to 200 feet below land surface, based on physiography, soils, and lithology, is about 33½ million acre-feet.

[41] Oliver, H. W., 1960, Gravity anomalies at Mt. Whitney, California: Art. 146 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B313–B315.

A. I. Johnson and D. A. Morris (Art. 16) have described the relation of volumetric shrinkage to clay content of the deposits in the Los Banos-Kettleman City area, San Joaquin Valley. They state that the volume of fine-grained deposits decreases continuously as the water content decreases until reaching the shrinkage limit, which is the transition point between the semisolid and solid states. This study is part of a broad-scale program on the mechanics of land subsidence being made under the direction of J. F. Poland.

A preliminary analysis of the hydrology of San Antonio Valley, Santa Barbara County, Calif., by K. S. Muir suggests that the perennial yield is in excess of 5,000 acre-feet. Much of the supply is now lost by evapotranspiration near the downstream end of the valley.

A reappraisal of the water supply of the Carpenteria and Goleta Basins, Santa Barbara County, Calif., by R. E. Evenson, K. S. Muir, and H. D. Wilson indicates that the perennial yield of both basins is somewhat larger than estimated 10 years ago. Subsurface inflow from the adjacent Santa Ynez Mountains, larger amounts of irrigation return water, and larger storage capacity of the deposits are being studied as the possible sources of the additional water.

Hydrologic studies in Washington

Studies of the White River valley train below Emmons Glacier, Mount Rainier, Wash., show a marked response of the train to flows produced by the high temperatures of July 1961.

A significant event of June 1961 was a mudflow that covered 50,000 square yards of the valley train near the glacier. The deposit contained an estimated 30,000 cubic yards of material from the prominent lateral moraine of the Emmons Glacier. The White River immediately began to remove the mudflow but left behind large boulders that could be construed by future observers as stream deposits.

ALASKA

Figure 2 is an index map of Alaska showing the boundaries of the regions referred to in the following summary of significant scientific and economic findings of recent geologic, geophysical, and hydrologic studies. Mineral deposits are discussed on pages A2 and A5, coal on page A10, floods on page A99, glacial geology on page A78, permafrost on page A81, highway geology on page A105, and Project CHARIOT on page A109.

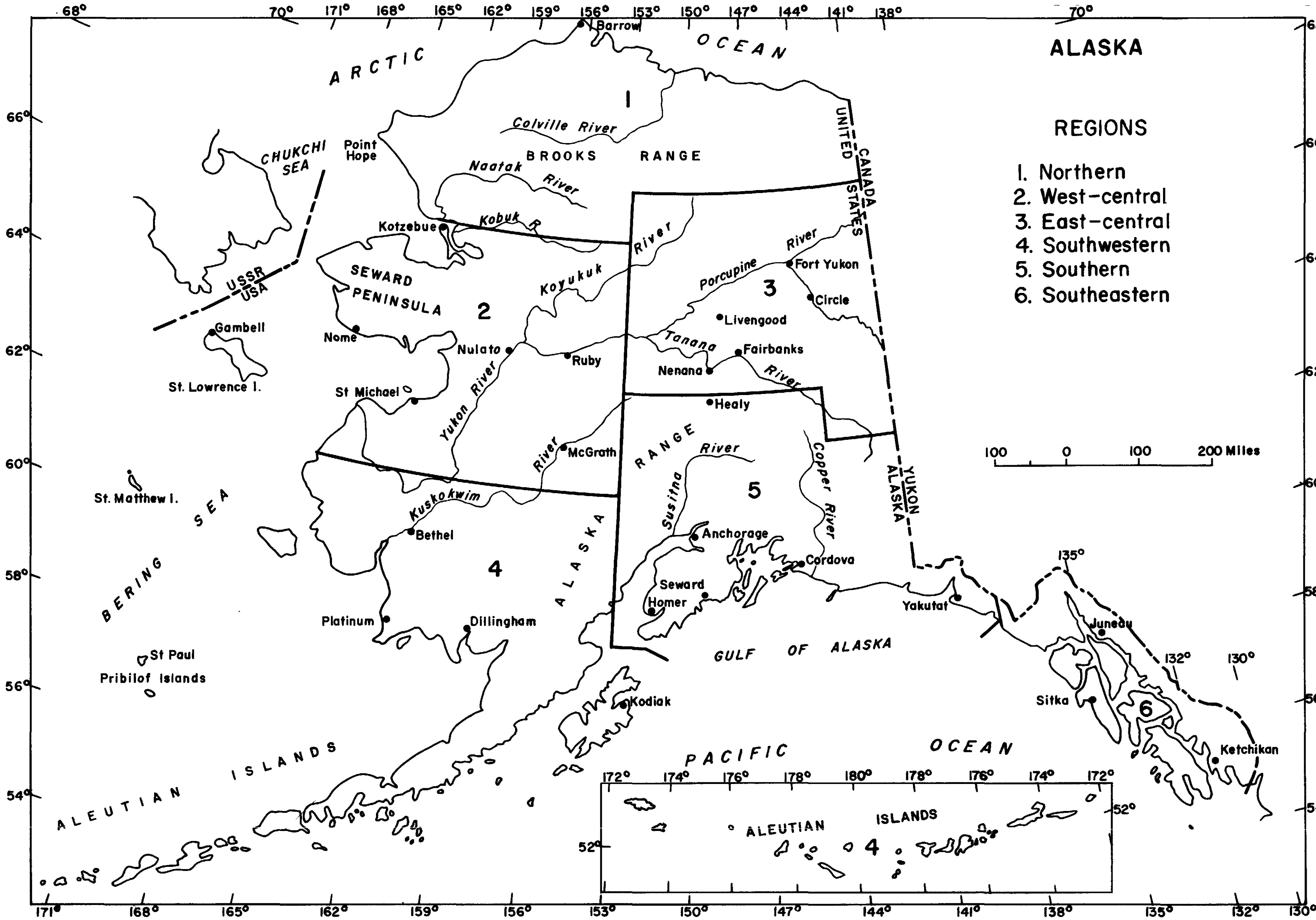

FIGURE 2.—Index map of Alaska showing boundaries of regions referred to on accompanying pages.

Northern Alaska

Regional studies of the structural knot at the northwest end of the Brooks Range province were recently begun by I. L. Tailleur. Lower Cretaceous and Jurassic rocks, comparable to those mapped in regions to the east and deformed along trends that swing from easterly to northerly going west, were found in the saddle between the nose of the DeLong Mountains and the Lisburne Hills. Within and along the east side of the Lisburne Hills the rocks are similar to those mapped at the CHARIOT test site and similarly exhibit imbricate faults. Coal-bearing rocks, intertongued with the base of the Mississippian Lisburne Group, and possibly subjacent graywacke that are unique to the Lisburne Peninsula, were found west of the Lisburne Hills. High-rank(?) bitumious coal in seams up to 10 feet thick that aggregate 70 feet of the carbonaceous section may have economic potential.

West-central Alaska

In evaluating previous aerial radiological measurement surveys, R. G. Bates obtained radioactivity values as high as 1,600 counts per second over stream gravels along streams draining to the north off the mountains south of Selawik Lake, Selawik quadrangle. These values indicate anomalous concentrations of radioactive minerals in the stream gravels and suggest that deposits of economic significance may exist within the drainage area.

On Seward Peninsula, detailed geologic mapping by C. L. Sainsbury has shown evidence of widespread thrust faulting in the York Mountains, and fossil collections indicate that the contact between Lower Ordovician argillaceous limestone and Middle Ordovician shales, shaly limestone, and arenaceous limestone probably is transitional. The Ordovician rocks are not conformable with the underlying slate, which probably is Precambrian or lowermost Cambrian in age.

Mapping by J. M. Hoare and W. H. Condon in the lower Yukon–Norton Sound region revealed that some of the areas previously mapped [42] as Quaternary basalt south of Norton Sound are interbedded calcareous sandstone and conglomerate of early Late Cretaceous age and andesitic volcanic rocks of probable Jurassic or Early Cretaceous age. Similar volcanic rocks of Mesozoic age commonly form the flanks of geanticlinal areas farther north around the edge of the Koyukuk Basin. This fact, plus the fact that the nearby conglomerate contains cobble-sized clasts of chert and quartzite of probable Paleozoic age, indicate a western source for some of the Cretaceous rocks that crop out between the Yukon River and Norton Sound.

[42] Dutro, J. T., Jr., and Payne, T. G., 1957, Geologic map of Alaska: U.S. Geol. Survey.

In the Candle and Selawik quadrangles, mapping by W. W. Patton, Jr., and A. R. Tagg (Patton and Grantz, 1962) suggests that the middle Cretaceous Koyukuk geosyncline was not, as previously supposed, a single depositional trough between the Brooks Range and the Yukon Delta, but consisted of a narrow east-trending trough along the Kobuk and upper Koyukuk Rivers and a larger southwest-trending trough that extended from the lower Koyukuk to the Yukon Delta. The two troughs were separated by the east-trending Hogatza High along lat. 66° N. The volcanic and granitic intrusive rocks of Late Jurassic and Early Cretaceous age now exposed along the geanticlinal trend were an important source of sediments in both troughs.

In the White Mountain area, near McGrath, C. L. Sainsbury and others report the existence of Middle (?) Ordovician and older rocks previously unknown in this area. The section consists of marine carbonate and clastic rocks approximately 4,500 to 5,000 feet thick dated by fossils as Middle(?) Ordovician and Silurian (?) in age. Along the Farewell fault these marine strata are in contact with 8,100 feet of quartz conglomerate of Cretaceous(?) age which may be correlative with the Cantwell Formation. The rocks are unmetamorphosed and may be important in petroleum exploration.

East-central Alaska

Analysis of fossils from the Upper Devonian clastic sequence in the central and eastern Brooks Range by J. T. Dutro, Jr., and W. A. Oliver, Jr., supports relations suggested by the physical stratigraphy. Work by W. P. Brosgé and others has indicated a complex sequence of intertonguing and intergrading units. Fossil assemblages of Frasnian and Famennian age are identified from a limestone-siltstone unit, a slate-sandstone unit, and, at the top, the Kanayut Conglomerate. These magnafacies apparently cut across time lines, becoming older in a general southward direction. Below this sequence the Skajit Limestone, of late Middle (?) and early Late Devonian Age, probably straddles the Middle-Upper Devonian boundary.

Reconnaissance of the Black River in east-central Alaska by E. E. Brabb has shown the need for a major revision of the geologic map of Alaska in that area. Bedrock exposures along the river from the United States-Canada border to Chalkyitsik (Fishhook) include quartzites of probable Precambrian age and basalt of Cenozoic age near Chalkyitsik, and limestone of Late Ordovician and Devonian age and argillite of Cretaceous(?) age near Salmon Village. Some of the coral faunas in the limestone are similar to the Bighorn-Red River faunas of the Rocky Mountain and Manitoba regions, according to W. A. Oliver, Jr.

Trilobite collections made by E. E. Brabb in northeast Alaska have been identified by A. R. Palmer and provide the first knowledge of early Upper Cambrian faunas in that part of the world. The Alaska trilobites reveal affinity to species from Queensland, Australia.

Discovery by gravimeter work of very thick deposits of low-gravity sediments in the basin west of Nenana by D. F. Barnes (1961) has attracted the attention of major oil companies. Land has been leased and a test hole will be drilled in early 1962. Field mapping in 1961 has proved conclusively that the hills a short distance to the southwest of the drilling site are underlain by nonmarine Tertiary beds found farther south in the foothills of the Alaska Range.

Southwestern Alaska

The gelogy of the lower Kuskokwim region has been summarized by J. M. Hoare (1961). The region includes part or all of 2 tectonically positive elements and part of 2 tectonically negative belts which were first formed in middle Mesozoic and older strata; the negative or geosynclinal belts contain strata ranging in age from Late Jurassic to Late Cretaceous which were derived locally from the positive elements and deposited under tectonically active conditions. Traces of copper, antimony, quicksilver, zinc, and gold were found by Hoare. Quicksilver and antimony mineralization was much less extensive than in the adjoining Central Kuskokwim region. Placer gold probably offers the best chance for expanding economic interest. The low porosity of the highly deformed rocks indicates a low petroleum potential.

Metamorphic rocks along the eastern margin of the Aleutian Range batholith that were formerly mapped as Paleozoic(?) are now considered to be of Triassic age, as a result of the work of R. L. Detterman. Rocks believed to be equivalent are found east of the contact-metamorphic zone; some of these unmetamorphosed rocks have a poorly preserved Late Triassic fauna consisting of *Halobia* sp. and *Monotis* sp. Detterman has also shown that the Iliamna region was the center of volcanism in southern Alaska during Early Jurassic time. The Talkeetna Formation in the Iliamna region consists almost entirely of lava flows, agglomerate, volcanic breccia, and tuff. North and south of the region this sequence of rocks contains thick interbeds of fossiliferous sedimentary rock.

R. E. Wilcox (1961) attributes the albite in the spilitic and keratophyric volcanic rocks of the Aleutian Islands mainly to albitization since emplacement of the rocks, rather than to primary crystallization from soda-rich magmas. He concludes this from the fact that the coexisting pyroxenes are normal types rather than soda rich as would be expected if their source magma had been soda rich.

Southern Alaska

In the McCarthy area D. J. Miller and R. S. MacColl have delineated widespread marine Cretaceous sedimentary rocks in the northern two-thirds of the McCarthy A-4 quandrangle. Supported by D. L. Jones' paleontologic studies, they have been able to demonstrate that 3 formations ranging from Albian to Maestrichtian(?) in age are represented, and that at least 1 unconformity is present. In the McCarthy C-5 quadrangle, geologic mapping by E. M. MacKevett, Jr., and M. C. Blake indicates that a section of marine strata approximately 8,500 feet thick, previously considered to be Late Triassic and Cretaceous in age, is Early, Middle(?), and Late Jurassic in age on the basis of fossil identifications by R. W. Imlay (Art. 133). In addition, they have discovered a previously unreported granodiorite(?) pluton cutting volcanic flows and intercalated sedimentary rocks near the base of the Wrangell Lava. Fossil leaves collected from continental sedimentary rocks intercalated with the basal Wrangell Lavas were dated as Oligocene by Jack Wolfe.

Foraminifera from the Matanuska Formation in the Squaw Creek–Nelchina River area of south-central Alaska are mainly of Campanian age, but the sequence studied by H. R. Bergquist (1961a) may range from late Turonian to Maestrichtian in age. Five tentative microfossil zones are indicated. According to A. Grantz, the formation contains several lithologic units and probably should be raised to group rank.

Issuance of two maps by A. Grantz (1961 a, b) completes the publication of geologic maps at 1:48,000 scale of the Nelchina area, in the western part of the Copper River basin, one of the possible petroleum provinces of Miller, Payne, and Gryc.[43]

Test drilling at Cordova has shown that glacial deposits extend to a depth of more than 140 feet in a small area between Eyak Lake and Orca Inlet, according to K. L. Walters. Sand and gravel beds penetrated by two test holes are of rather low permeability but should yield sufficient water to supply the city. Cordova for many years has used a surface-water supply, which, during the winter months entered the distribution system at a temperature of about 32°F. The groundwater temperature is about 42°F and should help to eliminate the problem of frozen water mains.

Southeastern Alaska

Study by J. A. Wolfe of a collection of the flora of Tertiary (Eocene and younger) rocks exposed on Admiralty Island [44] has shown that the coal-bearing rocks

[43] Miller, D. J., Payne, T. G., and Gryc, G., 1959, Geology of possible petroleum provinces in Alaska: U.S. Geol. Survey Bull. 1094.

[44] Lathram, E. H., Loney, R. A., Berg, H. C., and Pomeroy, J. S., 1960, Progress map of the geology of Admiralty Island, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-323.

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near Kootznahoo Inlet were deposited in a continuous sequence beginning in latest Eocene time. The youngest plants collected, which are of late Oligocene age, are overlain by a considerable thickness of sedimentary rocks that may, therefore, be of Miocene age. Further, the volcanic rocks on the south end of the island are underlain by plant-bearing beds of late Eocene age, and one collection from the volcanic rocks is of middle Oligocene age. Hence, the volcanics were extruded at the same time as sediments were being deposited in the Kootznahoo Inlet region.

During regional mapping on Chichagof and Baranof Islands, R. A. Loney, H. C. Berg, J. S. Pomeroy, and D. A. Brew found fossils of Jurassic or Cretaceous age on Emmons Island in Hoonah Sound, southern Chichagof Island, in slate and graywacke interbedded with volcanic rocks. These rocks were previously mapped as a part of the belt of Paleozoic rocks called the Prince of Wales geanticline by Payne.[45] This occurrence of Mesozoic rocks within the geanteicline tends to substantiate the suggested Mesozoic age for the chert, slate, graywacke, and greenstone sequence in northeastern Baranof Island (U.S. Geological Survey, 1961w, p. A43). This sequence is exposed about 15 miles to the southeast of Emmons Island along the regional structural trend and near the axis of the Prince of Wales geanticline. Thus, the areal extent of Paleozoic rocks may be greatly narrowed in the vicinity of southern Chichagof and northern Baranof Islands, and Mesozoic rocks may have originally extended eastward entirely across the Prince of Wales geanticline in this area, connecting with an abrupt westward salient of the eastern belt of Mesozoic rocks (Seymour geosyncline) near the southern tip of Admiralty Island.

The North Bradfield River iron prospect, examined by E. M. MacKevett, Jr., consists of several magnetite-rich bodies of pyrometasomatic origin that are localized in skarn. The skarn is part of a sequence of metamorphic rocks consisting mainly of gneiss, granulite, schist, and marble that forms a northwest-trending roof pendant within the composite Coast Range batholith.

MacKevett also reports that the Sumdum copper-zinc prospect is on numerous sulfide replacements and disseminations localized in gneiss and schist, and less extensively in fault zones. In order of general decreasing abundance, the sulfide minerals are pyrite, pyrrhotite, sphalerite, chalcopyrite, and bornite.

Cenozoic stratigraphy of Alaska

A remarkably complete record of Pleistocene climatic fluctuations, sea-level changes, and glacial events is preserved along the coasts of Seward Peninsula and Kotzebue Sound in western Alaska. Field investigations by D. M. Hopkins, D. S. McCulloch, and R. J. Janda (1962) and studies of the molluscan fauna by F. S. MacNeil demonstrated that "Submarine Beach," "Third Beach–Intermediate Beach," and "Second Beach," the three well-known marine units at Nome, are probably of Pliocene and Pleistocene, Aftonian (First Interglaciation) and Sangamon (Third Interglaciation) age, respectively. The presence of a fourth marine unit, "Fourth Beach," was confirmed at Nome and it was tentatively correlated with a newly discovered and highly fossiliferous marine deposit of definite Yarmouth (Second Interglaciation) age exposed on the shores of eastern Kotzebue Sound. Paleobotanical studies had previously shown that taiga (northern forest) vegetation extended into these tundra regions during the Sangamon interglaciation interval and during a brief warm period about 10,000 years ago. Additional palynological studies by Estella Leopold have now shown that during Submarine Beach (Pliocene and Pleistocene) time, pine, fir, and hickory grew near Nome in addition to species now characteristic of the taiga of central Alaska. Although the vegetation and the molluscan faunas have changed appreciably during the interval of time represented by the Pleistocene sediments at Nome and in the Kotzebue Sound area, the foraminiferal fauna has changed little, if at all; nearly all the species recognized in a series of specimens studied by Patsy Smith, representing all of the marine units recognized in the Nome-Kotzebue Sound area, live in adjacent waters at the present time.

Paleontological and stratigraphic studies carried out during the last decade have resulted in radical changes in the age assigments of Alaskan Tertiary marine and nonmarine sediments; the results are summarized in a recent publication by F. S. MacNeil and others (1961). Palynological studies recently conducted by Estella Leopold have contributed further to the solution of correlation problems, especially in the later part of the Tertiary period, and have begun to reveal the broad outlines of the developmental history of the tundra and taiga vegetation in the American Arctic. Pollen floras of probable Oligocene age consist dominantly of broad-leafed tree genera now restricted to temperate latitudes. Pollen floras of probable late Miocene or early Pliocene age consist chiefly of coniferous-tree genera, some of which are now restricted to more temperate latitudes. Several species of broad-leafed trees are also present. Pollen floras of probable Pliocene and Pleistocene age consist chiefly of pine, spruce, and fir with smaller quantities of pollen from broad-leaved trees that are alive today in central Alaska; but hickory—a genus now nearly restricted to the eastern part of the conterminous United States—is also present

[45] Payne, T. G. (compiler), 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–84.

in small but significant quantities. It appears that the northern vegetation has developed largely by slow subtraction of tree species incapable of surviving in a severe climate, with an accompanying proliferation of shrubby and herbaceous plants.

Recent stratigraphic and paleontological studies of radiocarbon-dated sediments of late Pleistocene age in the Tofty Placer districts by C. A. Repenning, D. M. Hopkins, and Meyer Rubin have shown that timberline was at altitudes of 600 feet and lower during various parts of the Wisconsin Glaciation in this part of central Alaska. Timberline evidently rose to its present altitude of 2,000 feet about 6,800 years ago.

A compilation being made by T. L. Péwé of the extensive deposits of loess in Alaska reveals that the deposits range in thickness from a film to more than 200 feet at Fairbanks and are as thick as those reported elsewhere in the United States. Further, this is one of the largest areas of loess in the United States. The loess is confined mainly to lowlands bordering the major rivers, all of which drained extensively glaciated areas in the past. In addition to the Quaternary loess, windblown dust is currently being deposited in many areas today.

HAWAII

Investigations in Hawaii during fiscal 1962 included observations on volcanoes, geologic and water-resources studies of specific areas, and the collection of basic records on surface and ground water. Water-resources work was carried on in cooperation with the Division of Water and Land Development of the Hawaii Department of Land and Natural Resources, and a part of the volcanologic studies was done in cooperation with the U.S. National Park Service.

Results of studies of aluminum desposits are discussed on page A6, a statement on clay resources is given on page A7, and results of recent paleomagnetic studies on lavas are presented on page A81.

Eruptions of Kilauea Volcano in 1961

In August 1960, soon after the great subsidence of the Kilauea dome in early 1960, J. P. Eaton and H. L. Krivoy detected new tumescence at tiltmeter stations over the summit area. The rate of tumescence remained low until late October 1960, when it accelerated rapidly immediately after a swarm of deep (50 km) earthquakes accompanied by swarms of shallower (10–15 km) earthquakes and by tremor. The rapid tumescence had abated by early November 1960, and from then until September 1961 it continued at a high but fairly constant rate. The tumescence between November 1960 and September 1961 could be attained by the addition of about 10 million cubic yards of magma per month to the magma reservoir within the volcano.

The first of three summit eruptions in 1961 began on February 24, in a small collapse pit on the floor of Halemaumau Crater and lasted less than a day. The second began on March 3 in the same pit and continued until March 25, filling the pit with 400,000 cubic yards of lava. This feeble outpouring of lava had little effect on the overall tilt picture, and the volcanic dome continued to inflate. The third eruption began on the night of July 10, 1961, spurting lava from a discontinuous rift extending halfway across the floor of Halemaumau. This eruption stopped on July 17. During the activity more than 17 million cubic yards of lava poured into Halemaumau.

The Kilauea dome continued to inflate, and on September 21, 1961, a swarm of large, shallow earthquakes began to emanate from the upper end of the east rift zone of Kilauea. By the following morning several small eruptions had occurred along the east rift, between 7 and 14 miles from the summit, and measurements at 2 tilt stations indicated that rapid detumescence of the summit area was in progress. In the next 2 days additional minor outbreaks, concurrent with strong faulting, took place farther down the rift zone, but all activity virtually had ceased by the night of September 24. Although the detumescence indicated a withdrawal of about 70 million cubic yards of magma from beneath the summit, less than 2 million cubic yards remained on the surface.

Petrographic studies by D. H. Richter and J. G. Moore of the 1961 lavas suggest that the lavas erupting at different altitudes along the rift zone came from different levels in the volcanic magma chamber. The lavas that erupted low on the rift zone contain abundant phenocrysts of olivine, but those high on the rift zone and in the summit area are devoid of olivine.

Lava lake in Makaopuhi Crater

The prehistoric 225-foot-deep lava lake in Makaopuhi crater on the east right of Kilauea Volcano is being studied by J. G. Moore. Detailed examinations of a vertical section through the lake-filling lavas have revealed a zone of horizontal silica-rich veins between 20 and 125 feet below the lake surface, and an accumulation of olivine in the bottom 90 feet of the lake.

Recent growth of Halemaumau Crater, Kilauea Volcano

A recent study by D. H. Richter, J. G. Moore, and R. T. Haugen (Art. 20), in cooperation with the U.S. National Park Service, has shown that landsliding has enlarged the area of Halemaumau Crater by almost 6 percent in the last 33 years. The average annual growth since 1928 has been about 1,700 square yards, equivalent to an average rate of recession of the rim of about 1.5 feet per year. The growth pattern has been neither consistent nor regular, however, and about 15 percent of the rim that existed in 1928 still is standing. Landsliding and rapid opening of cracks peripheal to the crater rim occur during detumescence of the Kilauea dome.

Lava lake in Kilauea Iki

Temperature studies in the 365-foot-deep lava lake formed in Kilauea Iki Crater during the 1959 eruption have been continued by W. U. Ault, D. H. Richter, and D. B. Stewart (1962). A second hole drilled through the lake's crust on April 13, 1961, entered molten lava at a depth of 29.7 feet. When the hole was deepened on October 4, 1961, it entered the melt at a depth of 35.0 feet. The maximum temperature measured in the molten lava was 1,106°C at the bottom of a probe forced 4 feet into the melt. Observations made during earlier and recent drilling show that the base of the crust is at the 1,065°C isotherm, regardless of depth. The 1,065°C isotherm moved downward more than 12 feet between August 1960 and October 1961, resulting in a crustal thickening of about 0.94 foot per month. The thermal gradient in October 1961 was 19°C per foot in the lower 23 feet of the crust and 5°C per foot in the melt. The rate of cooling of the melt at a depth of 39.2 feet during a 22-day period was 0.5°C per day.

Gravity and seismic-refraction studies on the surface of the lava lake have been started by H. L. Krivoy and J. P. Eaton. The thickness of the lake's crust as determined from seismic data is in accord with the thickness found in drilling. A preliminary magnetic survey by R. W. Decker shows relatively uniform vertical magnetic intensities over the central part of the lake, and extreme changes of more than 5,000 gammas along the margin of the lake.

Gravity studies

Reconnaissance gravity studies of the Island of Hawaii, begun in 1960 by H. L. Krivoy and J. P. Eaton (1961), have been extended by Krivoy and R. R. McDonald to cover most of the northeast half of the island. Local Bouguer anomalies of as much as +70 milligals have been found to overlie the summit areas of the two active volcanoes, Kilauea and Mauna Loa, and the dissected dome of extinct Kohala Volcano. The anomalies appear to be attributable to a complex of dense intrusive masses within the cores of the volcanoes. On Mauna Kea, data suggests that a high positive anomaly overlies the south flank of the volcano rather than its present summit area. D. R. Mabey and W. T. Kinoshita completed gravity coverage of Hawaii in early 1962 and made a regional gravity survey of the island of Maui.

Ground water in southern Oahu

Studies by F. N. Visher in southern Oahu show that increased pumping in the area has resulted in a lowering of the fresh-water head by about 3 feet. The lowering of the head has resulted in a decrease in natural ground-water discharge that is roughly equal to the increase in pumping. The long-term pattern of fluctuations of the water level measured in a deep piezometer extending into salt water under the fresh-water lens is about the same as that in nearby fresh-water wells. The water level in the deep piezometer was as high as 3 feet above sea level in 1958 and dropped to as low as 2 feet below sea level in 1961. The salt water that this piezometer measures apparently has poor hydraulic connection with the ocean. This poor connection may greatly retard the salt-water encroachment that would be expected to result from lowering of the fresh-water head.

Ground water in the Waianae district, Oahu

In hydrologic studies in the Waianae area of Oahu, C. P. Zones finds that the flow of ground water into streams and thence into the sea is small. The presence of brackish ground water under the coastal lowlands indicates that the discharge of ground water directly into the sea also is small. The major natural discharge of ground water is by transpiration through phreatophytes growing in the lowland. Most of the wells in the area also are in the lowland, where they compete with the phreatophytes and where withdrawal of fresh water has caused sea-water intrusion. Eventual maximum development of the fresh-water lens probably will be in wells drilled farther inland where the lens is relatively thick and the water table is too deep for large withdrawal by phreatophytes.

Water resources of windward Oahu

Studies by K. J. Takasaki, George Yamanaga, and E. R. Lubke (1962) on the windward (northeast) side of Oahu show that the minimum base-flow water supply in the area, before diversion and use, is about 82 mgd. (million gallons per day). The flow available for development, after diversion, is about 38 mgd. Most of the ground water in the area appears in streams before it flows into the sea.

In an analysis of records of flow of streams on windward Oahu, G. T. Hirashima (Art. 108) found evidence that the excavation of a 1,200-foot water-development tunnel in the valley of Haiku Stream caused a reduction in the base flow of Kahaluu Stream 2½ miles away. The valleys of the two streams, which are transverse to the axis of the Koolau Range, cut deeply into dike compartments containing high-level ground water. Draining of the ground water by the Haiku tunnel caused a shift of the ground-water divide toward and a reduction of ground-water discharge into Kahaluu Stream.

Rain-catchment studies

Preliminary studies of records of runoff from an artificial catchment in the North Kona district of Hawaii by D. E. Havelka and S. S. Chinn show that about 84 percent of the rainfall on the catchment can be recovered. The average yield from the quarter-acre catchment, which is in an area having a mean annual rainfall of about 80 inches, was about 2,000 gallons per day during the period 1958–61. Continuous supplies of 600 to 2,000 gallons per day from the catchment would require storage capacities ranging from 60,000 to 240,000 gallons.

INDIAN RESERVATIONS AND NATIONAL PARKS

Geologic and hydrologic studies in Indian Reservations

A hydrogeologic study of the Pine Ridge Indian Reservation, S. Dak., recently has been completed by M. J. Ellis. Results of the study indicate that the Arikaree Formation, of Miocene age, is the principal aquifer there, and that wells developed in this aquifer will yield up to 100 gallons per minute. In areas where the Arikaree Formation is not present, moderate quantities of ground water are available in alluvium of the White and Cheyenne Rivers and from undrained gravel terraces capping sediments of the White River Group, of Oligocene age.

An investigation of the Milk River valley in the Fort Belknap Indian Reservation, Mont., by W. B. Hopkins and O. J. Taylor indicated that most ground water from post-Cretaceous rocks is too saline for use. Water from the Cretaceous Judith River Formation contains considerable dissolved solids but is usable. The irrigated land is waterlogged because it is underlain by 30 to 40 feet of relatively impermeable fine-grained flood-plain deposits. These deposits are underlain by sand containing artesian water. Studies indicated that reducing the artesian pressure by pumping or draining would not alleviate waterlogging of the overlying deposits, but that reducing the artesian pressure by pumping from a few sand lenses in the flood-plain deposits would reduce waterlogging locally.

F. J. Kleinhampl reports that springs watering the Duckwater Indian Reservation, northern Nye County, Nev., issue from a terrace comprised of tufa and travertine that was originally a sinter deposit. This deposit has an area of about 2.5 square miles with a maximum length of about 3 miles and a width of 1.5 miles. The thickness is unreported, but areally it ranks among the large thermal-spring deposits of the United States.

P. W. Johnson has completed a study of the character and thickness of exposed volcanic flows in the vicinity of Hotosan Vo Village (Charco 27), Papago Indian Reservation, Ariz. The study was aimed primarily at establishing a suitable water supply for domestic use. A test well was drilled through a series of volcanic flows to a depth of 716 feet. Potable water under artesian pressure and of sufficient quantity was found at 625 to 650 feet and rose to 575 feet in the well.

G. A. Dinwiddie and W. S. Motts recently have completed a study of the hydrogeology of parts of the Acoma and Laguna Indian Reservations, N. Mex. They report that ground water in sufficient quantities for irrigation requirements and domestic supplies is available both in alluvial and basalt aquifers of the Rio San Jose valley and in tributaries to that valley. Additional but smaller supplies may be developed in the more permeable parts of the Tres Hermanos Sandstone Member of the Mancos Shale. Ground water in the alluvial and basalt aquifers near the streams is hydraulically continuous with water of the streams. Inasmuch as the Rio San Jose is a perennial stream in the stretch between McCartys, N. Mex., and the western boundary of the Acoma Reservation, aquifers in this reach are best supplied with water. This reach, therefore, is the most favorable area for development of additional large water supplies.

J. B. Cooper reports that the development of sources of ground water in southeastern McKinley County, N. Mex., for use by Navajo Indians living off the main reservation, is of great benefit. Since 1958 the Navajo Tribe, on the basis of hydrogeologic information supplied by the Survey, has developed an accelerated work program by means of which a number of successful new wells have been drilled and many long-used springs have been cleaned and rehabilitated.

The Ojo Alamo Sandstone, the Nacimiento Formation, and the San Jose Formation contain thick beds of sandstone in the southern part of the Jicarilla Apache Indian Reservation, N. Mex., and in adjacent regions to the south and west, according to E. H. Baltz, S. W. West, and S. R. Ash (Art. 171). The cumulative thickness of sandstone ranges from 80 to 1,840 feet, and a well tapping all the sandstone possibly would yield as much as 3,500 gallons per minute.

Ground-water study in Grand Teton National Park

An investigation near Jackson Lake, Grand Teton National Park, Wyo., by E. D. Gordon has revealed that moderate quantities of ground water of suitable quality for domestic and public supplies are available from Quaternary rocks along the east side of Jackson Lake. Larger ground-water supplies of similar quality are available from alluvium in part of the Pilgrim Creek Valley near Jackson Lake.

PUERTO RICO

The Geological Survey is carrying out a continuing investigation in cooperation with the Department of Industrial Research of the Puerto Rico Economic Development Administration to prepare detailed geologic maps and to study the mineral resources of Puerto Rico.

Preliminary geologic map

A geologic map of Puerto Rico has been compiled by R. P. Briggs at a scale of 1:240,000. Although the map has not yet been published, it is on open file and available for public use.

In the mountainous central core volcanic and sedimentary rocks of Early and Late Cretaceous and early Tertiary age are cut by numerous large faults and intruded by several plutons of dioritic rocks and by serpentine. Dipping gently seaward on the northern and southern flanks of the core are slightly deformed marine limestone and clastic formations of Oligocene and Miocene age. A wide variety of surficial formations mantle the older rocks, especially along the coasts of the island. Of special interest are widespread deposits of sand and clay that cover much of the northern coastal belt. Briggs (1962) believes that these sands were deposited by a retreating sea and then were trapped in a developing karst topography and thus could not be removed by surface runoff.

Limestone

The limestone sequence of northern Puerto Rico contains lenses of sand and gravel deposited as river-mouth bars and on river flood plains during late Oligocene and early Miocene time. Many of these lenses are due north of the headwaters of major rivers that now cross the limestone belt many miles from the lenses. W. H. Monroe (1962b) believes that these headwater reaches are as old as Oligocene, and that extensive multiple stream piracy has since diverted them. The thick Aymamón Limestone near the top of the sequence consists of chemical-grade limestone, 95 to 99 percent $CaCO_3$ (Monroe, 1962a), that apparently was deposited at a time when Puerto Rico had been eroded to a low island from which streams were removing very little debris.

Large quantities of a marble-like algal limestone of early Tertiary age are available in southern Puerto Rico in the Coamo and Salinas quadrangles (Glover, 1961a, b).

Aerial radioactivity survey

An Aerial Radiological Measurement Survey (ARMS) of Puerto Rico was made in November and December 1961 as part of a cooperative program with the Division of Biology and Medicine, U.S. Atomic Energy Commission. The radioactivity of the island has a wide range; initial study reveals delineation of several broad geologic features by aerial radioactivity measurements. The Utuado and San Lorenzo plutons, both of granodioritic composition and of Cretaceous or Tertiary age, have low to moderate levels of radioactivity. Adjacent to the plutons, Lower(?) Cretaceous rocks have low radioactivity and Upper Cretaceous rocks have low to moderate radioactivity. Moderate to high levels of radioactivity were measured over Tertiary calcareous rocks in the northwest part of the island. These levels have no immediate geologic explanation, as they trend north-south over the east-west trending Tertiary rocks.

Hydrologic studies

Peak discharge of streams in Puerto Rico may exceed the 100 percent Meyer rating and they rank with the highest known peaks in the world. Base flow of the streams ranges between 0.3 and 1.0 cubic feet per second per square mile in much of the interior upland area, but may be as low as 0 in the south coastal plain and as high as 2.0 cfs per square mile in the wettest mountains. Calcium and bicarbonate are the predominate ions in the water. Sediment discharge in some streams appears to be in the magnitude of 1,000 to 6,000 tons per square mile annually.

Production of more than 2,000 large wells individually ranges from about 0 to 4,000 gallons per minute. The low-producing wells generally are in the interior upland area and the high-producing wells generally are in the coastal lowlands area, particularly between Ponce and Patillas. Dissolved solids in ground water commonly are in the range of 65 and 250 parts per million. Salt-water intrusion is not a significant problem.

About 818 million gallons per day of surface water and about 257 mgd of ground water was used in 1960 for all purposes. Of the 69 inches of average annual rainfall on Puerto Rico, about 23 inches may be called the controllable supply, of which only a little more than 3 inches, or about 14 percent, was used consumptively in 1960. Most of the major rivers are not fully exploited, considerably more ground water can be pumped, and the total available supply is adequate for anticipated needs. The quality of the water is good for almost all purposes.

A preliminary appraisal of the water resources of the Jobos area is presently underway on Puerto Rico's south coast between Salinas and Guayama. The area is a coastal plain, mantled by alluvial gravels and clays overlying fractured and creviced bedrock. The alluvium is less than 50 feet thick at the east end of the area and more than 250 feet thick near the west end. Much of the streamflow from the hinterland enters the ground-water aquifers at the north edge of the plain and is generally released to the stream channels near the sea where the water table intersects the ground surface. The aquifers have very high coefficients of transmissibility, and about 40,000 to 50,000 acre-feet of ground water is pumped annually in this relatively small area. Because of the seasonally large streamflow and the local rainfall (averaging 45 inches annually), however, the water table throughout the area has shown no indication of decline over the last 30 years.

WESTERN PACIFIC ISLANDS

During the past fiscal year, the U.S. Geological Survey continued analyses of data and specimens collected during detailed field surveys of selected islands within the western Pacific Ocean between 1946 and 1958 (Fig. 3).

Preliminary results of surveys of 11 islands and island groups which were cooperative projects of the U.S. Geological Survey, the U.S. Army Corps of Engineers, and other agencies, have been published in a limited-edition series of "Military Geology Reports" that have recently been distributed to selected public and university libraries in the United States. Results of present studies are adding new information that will be useful in developing resources and interpreting the geologic history of an oceanic area comparable in size to that of the conterminous United States.

Hydrologic studies during the past year were limited to Guam, American Samoa, and Angaur Island (Palau Islands).

Marine geology of Guam, Mariana Islands

K. O. Emery [46] has made a detailed study of the offshore slopes, reefs, Cocos Lagoon, and the shoreline of Guam. He reports the existence of 4 distinct submarine terraces that are nearly continuous around the island at depths of 55, 105, 195, and 315 feet. The terraces have veneers of loose shallow-water calcareous sediments that have probably been derived from the reef edge. The reef is incised by large channels that appear to have a close relation to the island's present drainage but are probably ancient features that have persisted during growth of the reef. Muddy fresh water now supplied by the streams floats on sea water above the channels, rather than flowing downward through the channels. Sediments within Cocos Lagoon at the south end of Guam consist chiefly of sands composed of coral and algal fragments. The abundance of sediment types differs from that of atoll lagoons of the Marshall Islands because of shallower depths and a larger ratio of reef to lagoon area. On reef flats, diurnal heating of sea water and photosynthesis may produce supersaturation and deposition of some calcium carbonate; however, the amount is small compared to deposition by organisms. At the shore, solution of limestone by sea water may result from vertical solution gradients at the water-limestone interface and may involve complexing of the calcium so that it does not enter diurnal reactions comparable to those on reef flats. Discharge of brackish ground water of low calcium carbonate content prevents formation of beach rock at many places along the coast and explains the relative paucity of this type of deposit at Guam as contrasted to atolls where less ground water of higher carbonate content discharges, and beach rock is abundant.

[46] Emery, K. O., 1962, Marine geology of Guam: U.S. Geol. Survey Prof. Paper 403–B.

Paleontologic studies

Paleontologic studies by W. S. Cole, H. S. Ladd, and others confirm earlier age determinations for the upper Teritiary limestones of the Palau Islands and permit reappraisal of the distribution and depositional history of these limestones. Tertiary *f* (upper middle Miocene) limestones appear to be confined to the southern end of the island group where they form the cores and highest elevations of the islands and are flanked by younger limestones. In the central part of the group, basal Tertiary *g* (upper Miocene) limestones are overlain and flanked by uppermost Tertiary and Quaternary limestones. Cole, Ladd, and Gilbert Corwin believe a close relation exists between tectonic movements of the Palau Islands arc, progressive growth and destruction of coral reefs, and present distribution of limestones within the island group.

J. H. Johnson (1961) describes and discusses 90 species of fossil calcareous algae, belonging to 16 genera, from holes drilled on Eniwetok, Funafuti, and Kita-Daitō-Jima of the western Pacific Ocean. The fossil algae have contributed notably to reef construction and, on the basis of habitats on existing reefs, have considerable value as paleoecologic indicators. The algal floras from Quaternary, Miocene, and Eocene units are distinct and with one exception have no species in common.

On the basis of distribution and abundance of smaller Foraminifera in Recent shallow-water reef and lagoon sediments from Onotoa Atoll, Gilbert Islands, Ruth Todd (1961a) recognizes two major distinctive habitats: surfaces and adjacent slopes of the reefs, and limesand bottom of the lagoon. In general, the Onotoa fauna shows a close correspondence in species composition to faunas of other shallow-water reef and lagoon areas of the central Pacific. Foraminifera tests within the stomach and gut contents of 22 fish suggest a rather localized feeding area for each fish.

Continued study of the subfossil pigs from Ishigaki, Ryukyu Islands, by F. C. Whitmore, Jr., which were

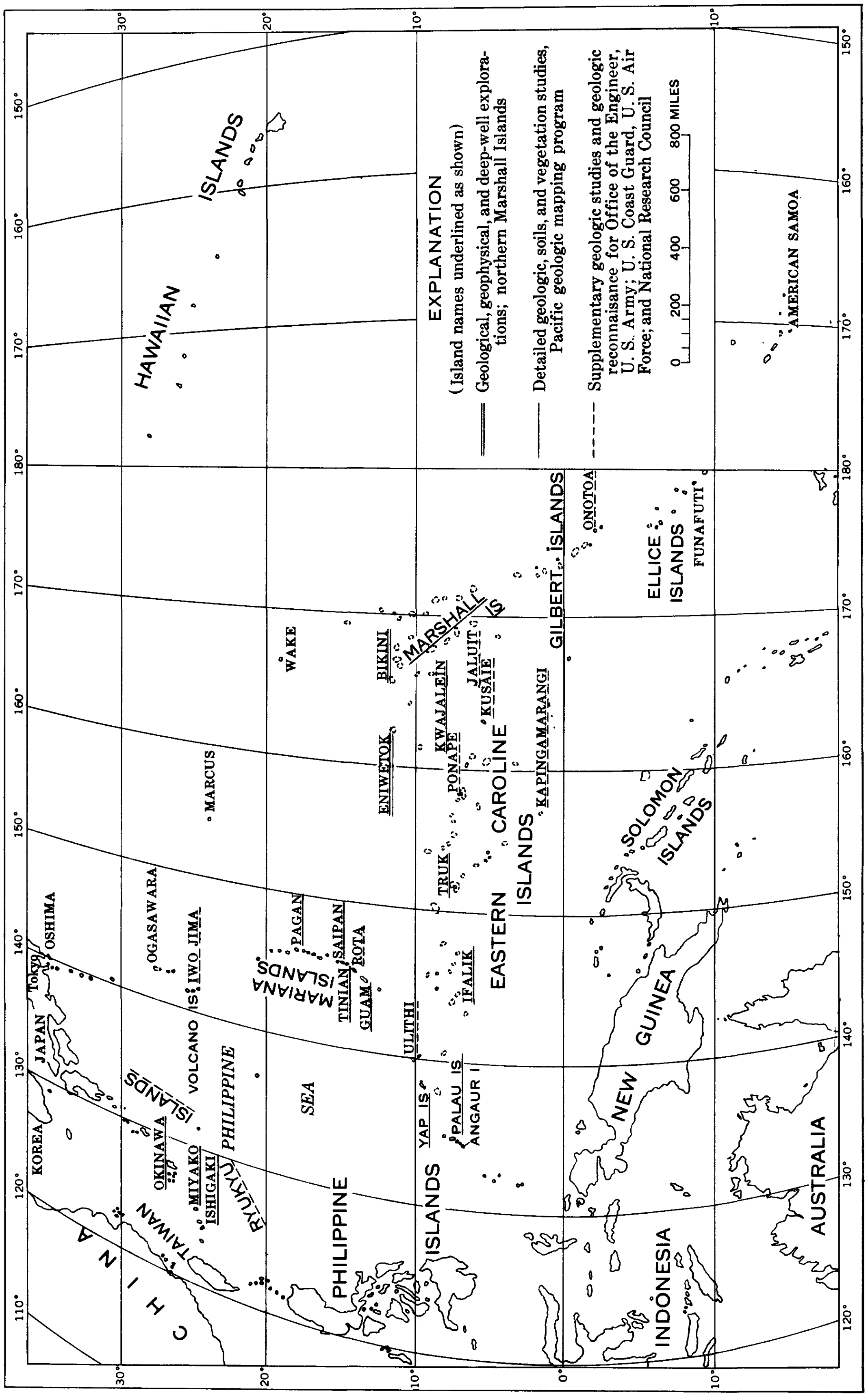

FIGURE 3.—Index map of western Pacific islands showing areas investigated by the U.S. Geological Survey.

first reported in Professional Paper 400–B (p. B372–B374) seems to indicate that they are closest to the living species *Sus taivanus* Swinhoe, which now inhabits northern Taiwan, rather than *Sus leucomystax* Temminck & Schlegel, the modern wild pig of Japan. It is not yet certain, however, whether these pigs migrated to the island or were introduced by early man.

Evidence for an earlier faunal connection between the southern Ryukyus and areas to the south and west is furnished by the presence on Ishigaki of the small deer *Metacervulus astylodon* (Matsumoto). This genus, occurring in beds of Pliocene and Pleistocene age, has been found elsewhere only in Shansi Province, China, and in Java. It probably migrated to the Ryukyus from China during a low stand of sea level in the Pleistocene. Its southern origin is further indicated by the fact that *Metacervulus* is found only south of Takara Strait, a deep passage crossing the arc which probably has formed a barrier to the migration of land animals since some time in the Tertiary.

Forty angiosperm pollen types, 3 fern spore types, and 2 kinds of simple algae have been recognized by Estella Leopold from drill cores on Eniwetok Atoll, Marshall Islands. The pollen-bearing sediments are of Miocene age, based on Foraminifera also present in them. Seventeen of the angiosperm genera have been identified; 6 of these now grow on the atoll, but 1 of these probably was reintroduced by man. Ten now exotic angiosperm genera identified by fossil pollen now grow in the western and (or) central Micronesia. High pollen density and the presence of shoreline algae in deep levels of drill holes lend supporting evidence to the hypothesis that the coral atoll has undergone subsidence since Miocene time.

Ground-water supplies in American Samoa

A reconnaissance study of Tutuila, Aunu'u Ofu, Olosega, and Ta'u Islands in American Samoa by D. A. Davis suggests that both high-level and basal ground-water supplies could be developed on most of the islands. The islands are volcanic in origin and are composed of lava flows, dikes, tuff, and breccia, and minor amounts of colluvium, alluvium, and calcareous sand and gravel.

Hydrologic studies on Guam

The water supply of Guam Island was studied briefly in 1961 by G. F. Worts, Jr. Guam is about 30 miles long and 7 miles wide, covering an area of roughly 200 square miles. The northern half of the island is a limestone plateau, which contains a basal fresh-water lens floating on salt water. Rainfall is about 100 inches per year, and little of it runs off—most recharges the fresh-water lens by sinking into the limestone or forming short streams that flow into sink holes. Shaft and tubes wells have yields in excess of 2,000 gpm, but many, particularly those near the edge of the island, are saline.

The southern half of the island is composed largely of volcanic rocks, which contain little ground water. The numerous small streams have extremely large discharges for their size, producing as much as 4,000 cfs per square mile according to S. H. Hoffard. One stream has been developed (the Fena Reservoir system) by the Navy as a source of water supply, and several others offer potential sources of supply when their development is required.

Total water use on the island in 1961 for a population of nearly 70,000 was approximately 11 mgd. Springs and wells in the northern part of the island supplied somewhat more than 3 mgd to military installations and a few residential tracts; diversions from springs, streams, and a few dug wells around the southern part of the island supplied considerably less than 1 mgd to the several municipalities and rural areas; and the Fena Reservoir system supplied about 7 mgd to Naval installations and to the Government of Guam for distribution to municipalities and rural areas in the northern part of the island. The Fena Reservoir system reportedly has a firm yield of 9 to 14 mgd, and therefore is capable of supplying the total current water requirements, except during extended droughts. The water-distribution system, however, would have to be enlarged at considerable expense to convey water to all principal water users on the island.

Saline-water intrusion on Angaur Island

Studies of Angaur Island by Ted Arnow (1961a) indicate that open-pit mining of phosphate ore created large water-table lakes, which became filled with saline water. It was determined that the earthy phosphate formed a seal over the underlying highly permeable limestone which contains saline water. Removal of the phosphate allowed the saline water to enter the excavations.

The possibility of the saline water spreading to surrounding areas and causing damage to agricultural land and the water supply was evaluated. To reduce the possibility of saline-water intrusion into the surrounding fresh-water aquifers, the excavations were back-filled with rubble. In less than a year recharge from rainfall substantially reduced the salinity, and a fresh-water lens had been established in the former sites of the saline lakes.

ANTARCTICA

A geologic-mapping program in Antarctica by the Geological Survey was begun in the 1960–61 austral summer and was continued in 1961–62 in cooperation with the U.S. Antarctic Research Program of the National Science Foundation. Areal geologic mapping at a scale of 1 : 50,000 has been done in the Thiel Mountains (formerly referred to as eastern Horlick Mountains) in the interior of the continent. Glaciological studies have also been made in the Thiel Mountains. A Survey coal geologist accompanied a party from Ohio State University in the Ohio Range of the Horlick Mountains. Studies in petrology, tectonics, coal geology, and glacial geology begun in previous years have been continued.

The topographic mapping of Antarctica, carried on as part of the U.S. Antarctic Research Program of the National Science Foundation, was expanded during fiscal year 1962. Six topographic engineers went to Antarctica during the 1961–62 austral summer to obtain geodetic control for topographic mapping, and one aerial-photograph specialist was assigned to the Navy in an advisory capacity. In addition to the conventional practice of using solar observations for position determinations, daylight observations were made on stars, with an expectation of greater accuracy in the final results.

Geology of the Thiel Mountains

A five-man Survey party has completed the areal geologic mapping of the Thiel Mountains (fig. 4). A. B. Ford, J. M. Aaron, R. W. Tabor, B. G. Andersen, and R. W. Elliott have found that hypersthene-bearing quartz monzonite porphyry comprising the main massif has been intruded by very coarse grained biotite granite porphyry. Pegmatite and aplite dikes are very rare. Petrographic studies by Ford and Tabor show that unusually euhedral porphyroblasts of cordierite have developed in the quartz monzonite. Indistinct light and dark layers forming local antiforms and synforms within the quartz monzonite suggest that it has been folded.

The age of the plutonic complex is unknown, but large samples were collected for absolute age determinations. The Devonian and younger strata that overlie crystalline basement rocks in the Horlick Mountains are not exposed in the Thiel Mountains. The southernmost bedrock outcrops, however, show abundant erratics of sedimentary rocks resembling those of the Horlick Mountains. The erratics lie on diabase, and therefore it is probable that later Paleozoic strata and related intrusive diabase are buried beneath plateau ice on the south flank of the range.

Weakly metamorphosed sedimentary rocks in the southernmost group of nunataks have been intruded by quartz diorite. Quartzite, argillite, and spotted argillite predominate. Sills of dacite occur locally. These rocks are mostly unfossiliferous, but Aaron found probable organic materials in black argillite at one locality. The sedimentary and related intrusive rocks are not folded or are only very gently folded, but they have been involved in high-angle faulting.

Glaciology and glacial geology of the Thiel Mountains

A network of stakes on the ice sheet was surveyed by B. G. Andersen during the 1960–61 season and resurveyed the following season to determine annual ice movement. Seasonal movements of the steeper glaciers were measured in the 1961–62 summer. Although final calculations have not been made, ice movement was found to be extremely slow. The annual snow accumulation during 1961 was about 1½ feet; stratigraphic studies in snow pits indicate that it has been about the same for the past 15 years. Erratics and glacial striations on nunataks show that the ice sheet has been at least 1,500 feet thicker than it is today.

The mean annual air temperature is about −37°C, as inferred from the temperature at the bottom of a 30-foot-deep bore hole. Daily summer air-temperature variation is generally less than 5°C, but daily variation of temperatures of rock surfaces which are shaded part of the day was found to be as much as 40°C and varied from about −15°C to about +25°C. Chemical weathering as well as mechanical weathering by frost action seem to be significant processes even in this polar environment.

Paleobotany and coal studies

Additional collections of fossil plants from the Ohio Range of the Horlick Mountains and from the Mackay Glacier area in Victoria Land by J. M. Schopf have added new elements to the flora. These include *Schizoneura*, *Vertebraria*, coniferous twigs, and cone scales. The rhizomes of *Vertebraria* attest to the local growth of vegetation, but "root" zones are not evident below coal beds. The new plants reinforce earlier tentative conclusions as to the probably Permian age of the Antarctic coal measures. Early Devonian psilophytic plants occur in dark shale intercalated between sandy fossiliferous marine beds in the Ohio Range. An alteration of littoral and paludal facies is indicated.

In the laboratory, reflectance studies of coal from beneath igneous sills show evidence of coke structure and indicate that the coke formed from high-rank bituminous coal. Further coal analytic data show variation in analytic values down to about low-volatile bituminous rank, depending on distance from igneous intrusion.

Fish plates were found by John Mulligan in 1961 in an erratic of black shale on the Mackay Glacier and are comparable with those described by Smith Wood-

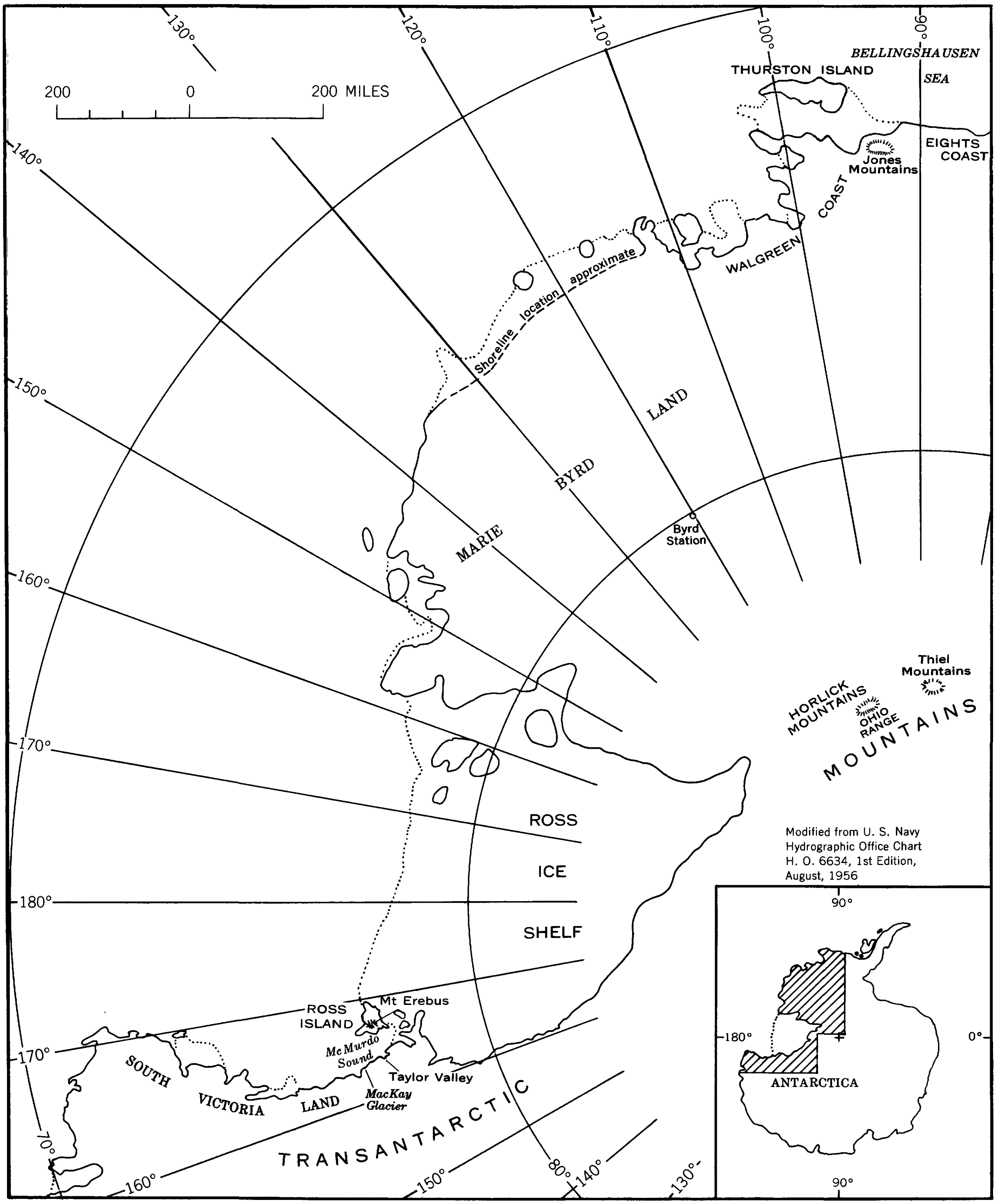

FIGURE 4.—Index map of part of Antarctica showing areas of geologic mapping, geologic studies, and geologic reconnaissance by the U.S. Geological Survey, 1957 through 1962.

ward[47] from the same area. This material probably indicates the existence of Upper Devonian deposits.

Reconnaissance geologic traverses

The occurrence of lithologically similar alkaline basalts and trachytes of probable Quaternary age in Marie Byrd Land, the Ross Island area, and South Victoria Land has been interpreted by W. B. Hamilton and E. L. Boudette to be a highly alkaline volcanic province petrologically, but not tectonically similar to the African rift valleys. This criterion along with the potassic character of the basement rock, the lack of a submarine trench, and an appropriate volcanic alinement, all in the province, preclude that the ice-submerged "islands" of Marie Byrd Land and the Ross Sea Islands are part of an andesitic island arc of the circum-Pacific type.

Geologic reconnaissance of the Eights Coast

Five areas of bedrock exposure were examined by A. A. Drake, Jr., a member of the U.S. 1961 icebreaker expedition along the Eights Coast of the Bellingshausen Sea. The principal rock present in all these exposures is diorite that apparently is the same unit described from Thurston Island by Craddock and Hubbard.[48] The unit is of batholithic size and has a maximum dimension of more than 120 miles. Specimens of granite or quartz monzonite collected from one exposure suggest that the batholith may have potassic differentiates. The age of this unit is unknown, but it is almost certainly not related to the Andean intrusives of the Palmer Penninsula that have an entirely different character. The batholith probably belongs to the series of Paleozoic intrusives so common in west Antarctica. Petrographic and petrochemical affinities have not as yet been determined. Inclusions of metamorphic rock were found within the batholith near lat 72°35′27″ S., long 95°07′00″ W. This rock is composed principally of high-calcium plagioclase and orthopyroxene (probably hypersthene) and has charnockitic affinities. The batholith is overlain by basaltic volcanic rocks in the Jones Mountains.

This expedition confirmed the presence of a number of islands in this part of Antarctica. These islands, however, are of plutonic rocks and not of volcanic rocks as had been postulated previously.

Saline features in Taylor Valley

W. B. Hamilton, I. C. Frost, and P. T. Hayes report (Art. 28) that a small ice platform lying at the north side of the snout of Taylor Glacier, between the glacier and Bonney Lake, has numerous small saline pools upon it, and the till at its edge is thickly encrusted with halite. The platform, probably an ice delta formed by refreezing of meltwater streams from the Rhone and Taylor Glaciers, has a fretted surface due to the accumulation of saline waters; the total relief is 6 feet. The surface is stained yellowish brown by minute granules of iron oxide, in striking contrast to the clean white ice of lake and glacier. Depressions contain sulfatic water and are floored by a precipitate of calcite and iron oxide. At the edge of the platform, insolation holes around boulders contain saline water. Evaporites, mostly halite, encrust the boulders and also form a surface crust and subsurface caliche in the till at the edge of the ice. A preliminary concentration of the solutions as a saline residuum after freezing is likely, the solutes remaining in the last freezing portion. Evaporation must control the precipitation of calcite, iron, and salts.

Age of moraines in McMurdo Sound area

The presence of ice cores in youthful-appearing moraines mapped by T. L. Péwé during the 1957–58 season indicates their considerable age. Ice-cored moraines as old as 6,000 years occur in the area. In addition, fully developed contraction-crack polygons with trenches 3 to 4 feet wide are present on the moraines. Such features probably take hundreds of thousands of years to develop. Mummified seals up to 2,000 years old have been found near and on these moraines, indicating a minimum age for the deposits.

Topographic field operations

W. H. Chapman, W. C. Elder, and E. R. Soza used electronic distance-measuring equipment to establish mapping control in the mountains between Hallett Station and Plunket Point, near the head of the Beardmore Glacier (fig. 5). In addition to the U.S. Navy logistics support furnished to all USARP field parties, this particular group was closely supported by a U.S. Army helicopter detachment. Successful completion of the 1,500-mile traverse resulted in the establishment of control for mapping 100,000 square miles of mountainous terrain.

While operating with a USARP party jointly fielded by the Universities of Michigan and Minnesota, T. E. Taylor established control along the west edge of the Ross Ice Shelf near the Nimrod Glacier, the Liv Glacier-Amundsen Glacier area, and Mulock Inlet.

C. G. Merrick, a member of the USARP Antarctic Peninsula Traverse, obtained geodetic positions for approximately 100 peaks in Ellsworth Land between the Jones Mountains and the base of the Palmer Peninsula. Several mountain ranges were observed and located,

[47] Woodard, A. S., 1921, Fish remains from the Upper Old Red Sandstone of Granite Harbour, Antarctica: British Antarctic ("Terra Nova") Expedition, 1910, Natural History Rept., Geol., v. 1, no. 2, p. 51–62.

[48] Craddock, Campbell, and Hubbard, H. A., 1961, Preliminary geologic report on the 1960 U.S. expedition to Bellingshausen Sea: Science, v. 133, no. 3456, p. 886–887.

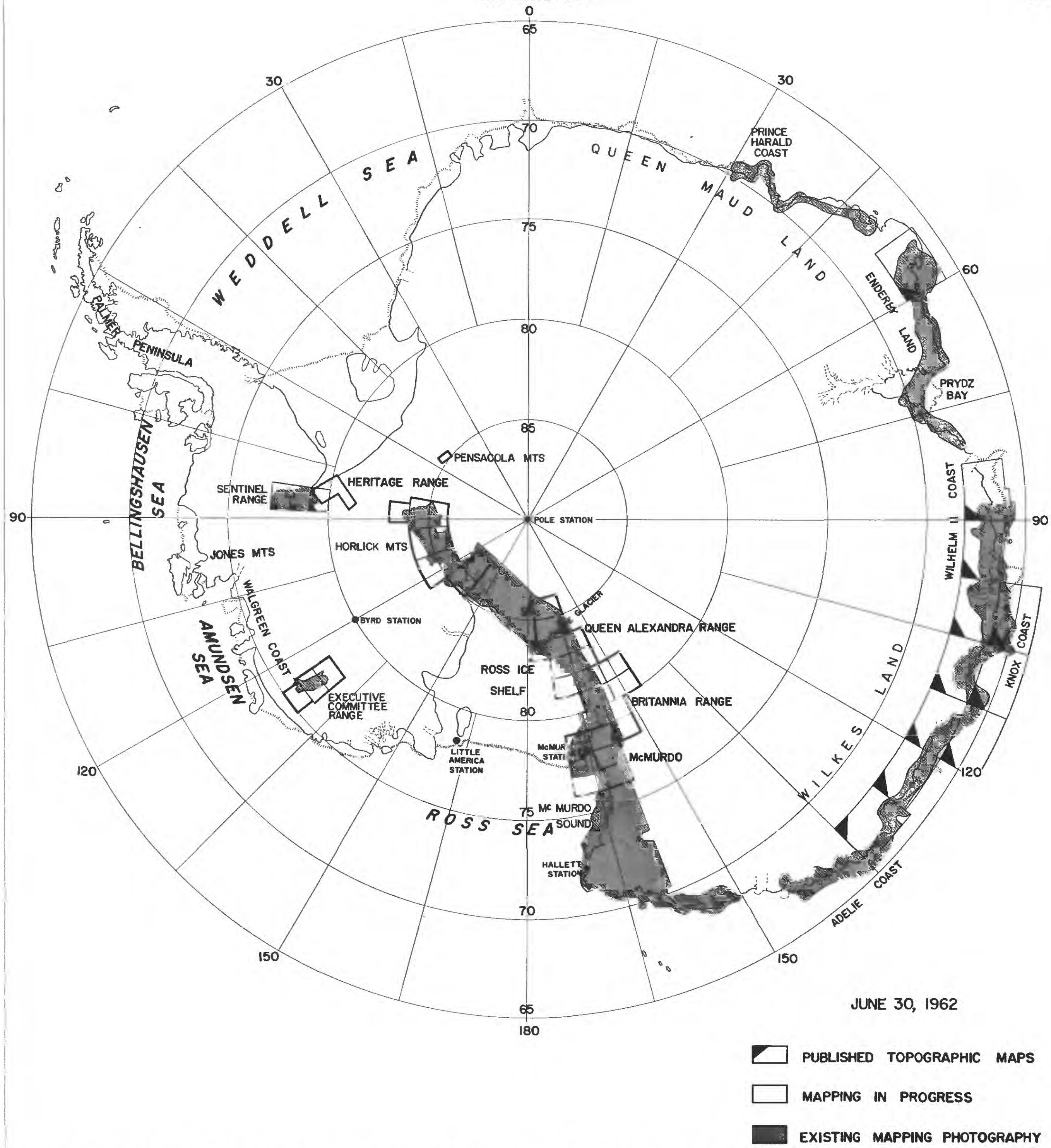

FIGURE 5.—Index map of Antarctica showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1962.

and it is thought that the Sweeney, the Latady, and the Lowell Thomas Mountains are among them. There is considerable variance between the positions of these ranges as reported from sightings by early explorers and these recently observed geodetic positions. It will be necessary to study the report of earlier sightings to correlate the conflicting name data.

R. D. Martin established horizontal control by triangulation and vertical control by spirit leveling for use by the U.S. Naval Hydrographic Office in the photogrammetric compilation of a large-scale map of Naval Air Facility McMurdo, the main U.S. base in Antarctica.

Stellar observations for geodetic position were made at the marker designating the South Geographic Pole by R. D. Martin and at the new Byrd Station by W. H. Chapman. The latter position was tied by electronic surveys to the old Byrd Station, the site of an observation made by Chapman during the winter of 1959. Both positions are on the moving polar icecap. An approximation of the annual rate of ice movement may be possible by comparing positions determined in different years.

Additional astronomic observations in Antarctica are reported on page A125.

Aerial photography

U.S. Navy Air Development Squadron Six obtained aerial photography in accordance with Geological Survey specifications. W. R. MacDonald was assigned to the Navy Photographic Laboratory at Christchurch, New Zealand, to advise on the quality of developed photography and to assist on planning and necessary reflights.

Early in the season, one of the three Neptune P2V's used for Antarctic photographic missions crashed at Wilkes Station, killing five men. Because of this loss, severe operational restrictions were placed on the two remaining aircraft. Final analysis of the season's photography indicates that an area of about 105,000 square miles was photographed acceptably for use in the Survey's mapping program.

Cartographic activities

Three 1:500,000-scale topographic maps along the coast of Wilkes Land were published, making a total of 11 sheets now available in this area.

Three 1:250,000-scale topographic maps of the Sentinel Range of the Ellsworth Mountains were published in shaded-relief editions. These sheets are the first of a series designed to cover those areas of interest to Antarctic scientists. Mapping at the same scale is in progress for 33 other maps covering the Horlick Mountains, Executive Committee Range, McMurdo area, Britannia Range, and Queen Alexandria Range (fig. 5).

Uncontrolled planimetric manuscripts are being compiled of part of the Pensacola Mountains, and of the Heritage Range of the Ellsworth Mountains, to support geologic investigations by the Survey and the University of Minnesota.

Antarctica relief model

Compilation was completed and a contract was let for a 2-layer multicolored plastic relief model of Antarctica, at a scale of 1:10,000,000 with a vertical exaggeration of 25:1. The lower part of the model will show the submarine floor, the subice topography, and ice-free mountain areas on the continent. The upper and removable section of the model, which will be semitransparent, will show the sea-level surface and the surface of the continental ice mass. The projections of mountain masses through the ice will also be shown on the upper section.

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

Under the auspices of the U.S. Department of State Agency for International Development, the Geological Survey continued to play an important role in supporting and furthering United States foreign policy by extending scientific and technical assistance to nations whose future development depends largely on full utilization of their source of greatest wealth—minerals and water. Programs undertaken or continuing in fiscal 1962 in 20 countries were fundamentally designed to assist in establishing permanent governmental units capable of carrying forward national mineral and water basic-data gathering and analysis activities. Such basic scientific data are now recognized as the foundation for sound economic development, enabling the expansion, diversification, and conservation of these resources for the ultimate benefit of the people.

The Geological Survey's activities are of several kinds: (a) geologic training of students of other countries, accomplished by assigning them to field parties and laboratories in the U.S., or by sending experienced American geologists to foreign universities or geological surveys as instructors or training officers; (b) advisory services in the establishment of geologic surveys; and (c) cooperative systematic geologic investigations of areas favorable for the occurrence of mineral and water resources.

Although the advisory and training activities are of great signifiance, they do not yield new geologic information directly and are not described here (see p. A167–168 for a list of the activities). Some of the new information from cooperative field studies abroad is here summarized with emphasis on items of broad scientific and economic interest.

Iron-ore deposits, Minas Gerais, Brazil

An ore control of the high-grade hematite deposits of the Quadrilátero Ferrífero has been established by recent geologic studies. It has been known for some years that folds in the itabirite host rock were an important structural control of the metasomatic high-grade hematite ore (66 percent Fe or more). Also known was that marked steepening of the lineation in the rocks was characteristic of some ore bodies. However, localization of several ore bodies, ranging in size to more than 200 million tons, still could not be explained, and it was thought that internal folding within the iron-formation localized these bodies. Now, mapping of the Moeda Plateau by R. M. Wallace shows that bodies of high-grade hematite were localized at the intersection of obscure cross folds, which occur in two systems, with the generally north-trending flanks of the major Moeda syncline. The lineation was steepened by this intersection. G. C. Simmons then recognized that ore occurred at crossfold intersections in the Brumadinho area, and J. V. N. Dorr recognized such relations in the Jangada-Samambaia area in the Serra do Curral. Thus, all the thoroughly explored, major deposits of high-grade hematite in the Quadrilátero Ferrífero are now known to be localized on or near the axes of folds and, in many cases, at the intersection of major and minor folds. Folds are both anticlinal and synclinal.

Lead-zinc deposits, Bahia, Brazil

R. F. Johnson (1960) has studied and reported on the Boquira lead-zinc deposits in south-central Bahia, Brazil. These deposits, among the largest known in that country, occur as veins in lenses of iron-rich metasedimentary rocks of probable Precambrian age. Extremely rich near-surface ozidized lead ore has furnished most of the production to date, but sulfide minerals have been found at depth.

Tin, tungsten, and copper studies, Bolivia

Among the several demonstration field projects currently under way in Bolivia are the geological investigations and mapping in the Cordillera Tres Crucos (Quimza Cruz), an important tin- and tungsten-producing area of great potential. A study of a part of the Altiplano copper belt, including 2,800 square kilometers of mapping at a scale of 1:50,000, has been completed. Two veins were discovered by Bolivian geologists, Henry C. Meyer and Jose E. Murillo, through geochemical prospecting, and three additional veins were discovered through electromagnetic studies.

Geomorphology and metallogenic map, Chile

Recent studies by Kenneth Segerstrom (Art. 93) indicate that the dune deposits, consisting of sand chains and barchans which extend from Chile's Pacific coast inland to the area northeast of Copiapó (Atacama Province), are derived from deflation of an elevated marine terrace. The terrace consists mainly of sandstones and coquina beds that rest unconformably on the granitic bedrock. The dune chains lie near the east margin of the deflated area and extend inland on a bearing of approximately N. 70° E., parallel to the dominant present-day wind direction.

A metallogenic map of Chile has been compiled jointly with the Instituto de Investigationes Geológicas and is now being prepared for publication.

Mineral deposits near Torreon, Coahuila, Mexico

Abundant deposits of industrial-grade gypsum in commercial quantities, located in the easily accessible border areas of the Sierra de Texas, were studied by B. H. Kent during the mapping of the San Pedro quadrangle. Transportation facilities are good and an adequate supply of gypsum is available for any extensive new industrial use in the Torreon area, State of Coahuila. The Sierra de Texas, in the central part of the quadrangle, consists of two formations: the Upper Cretaceous Indidura Formation, conformably overlying the Lower Cretaceous Aurora Limestone. Numerous vein deposits of high-quality barite and fluorite were found throughout the range, although none contains adequate ore to be considered commercial.

Mineral-resource studies in Libya

The compilation of a new base map and a geological map of Libya at scale of 1:2,000,000, in addition to the completion of a summary report on the geology and mineral resources of Libya (exclusive of petroleum), marked the end of cooperative field investigations begun in 1955. Many detailed geological data were supplied by private oil concessionaires through the Petroleum Commission of the Ministry of Petroleum Affairs in Libya. During the course of the work a financially self-supporting minerals-testing laboratory (chemical) with a 10-man staff was permanently established.

Ground-water in the Libyan desert of western Egypt

Ground-water investigations to date in the New Valley project in the Libyan desert of western Egypt have revealed 3 or more thick and productive artesian sandstone aquifers at depths of 100 to 700 meters beneath the Kharga Oasis. These aquifers yield water generally containing less than 250 milligrams per liter of total dissolved solids. Twenty of the projected 27 wells have been completed for geohydrologic exploration and pilot development. All wells in the lower part of the oasis flow with artesian heads as much as 100 feet above land surface. The total developed flow from the 20 wells measured approximately 120,000 cubic meters per day.

Ground-water investigations in Kordofan Province, Sudan

Cooperative ground-water reconnaissance of Kordofan Province, Sudan, has shown that ground water occurs in deeply weathered Precambrian crystalline rocks over about 55 percent of the province and in Cretaceous sandstone and Pliocene and Pleistocene sand throughout the remainder of the area. In most places, ground water is of good to fair chemical quality; in some parts of the province, however, the water is not potable.

Iron deposits of Yugoslavia

The principal iron deposits of Yugoslavia, in the Republic of Bosnia-Hercegovina, have been examined by Carl Dutton. At Vares, near Sarajevo, a hematite layer with an average thickness of 50 feet and an underlying siderite layer with an average thickness of 200 feet are gently to moderately inclined, are part of a sequence between thrust faults, and are separated into three main ore bodies by other faults. At Ljubija, in the northwestern part of the republic, a siderite layer with an average thickness of 150 feet is gently folded, faulted, and locally is extensively altered to limonite; other limonite deposits as much as 135 feet thick appear to be in disconnected basins on the bedrock surface and are believed to be transported and reaccumulated material.

In the eastern part of the Republic of Macedonia, magnetite deposits in tilted sandstone near andesite occur in an area 2,500 feet by 150 feet and are being developed for concentration. In the western part of the republic, chamositic layers in phyllite near Kicevo are as much as 60 feet thick and are being developed for possible use. The strata are gently folded and complexly faulted.

In the southern part of the Republic of Serbia, 2 deposits that contain magnetite lenses as much as 150 feet long and 60 feet wide in marble are being explored and developed for probable production.

Iron deposits of large tonnage, but of only possible potential value because of excessive amounts of nickel and chromium, occur along the boundary of Bosnia-Hercegovina and central Serbia and in southern Macedonia. Chamosite and limonite are at the first locality and magnetite, hematite, and limonite at the second. The deposits are on or near serpentinized peridotite from which they were derived and reaccumulated chemically and mechanically in predominantly clastic strata.

Cooperative mineral exploration and paleontologic studies in Pakistan

Reconnaissance investigations of the Hazara District, West Pakistan, by S. T. Ali, J. A. Calkins, T. W. Offield, and K. W. Stauffer, indicate the presence of a number of promising mineral occurrences. Most notable are glass sands (metamorphosed quartzose sandstones containing variable amounts of carbonate) at Manda Kuchha, and bedded iron and manganese deposits at Galdanian. Reserves of glass sand are estimated to be 155 million tons. The iron and manganese deposits occur as hematite and manganese-rich beds within a persistent red-bed sequence. Reserves are unknown. Other promising mineral commodities are kaolin, scheelite, and pegmatite minerals, including beryl. Analyses of heavy minerals from stream sands indicate high concentrations of scheelite from the drainage basin southeast of Batgram.

A detailed survey of the Makarwal coal field in West Pakistan was recently completed by Ibrahim Shah and W. Danilchik. This work indicates that the small but important coal field is nearly exhausted of its developed reserve, but that another 3 million long tons remains to be developed above the water table. The total remaining reserve in all categories is 19,217,000 long tons.

Beach placers containing monazite, ilmenite, zircon, and other heavy minerals extend 100 miles southeastward along the shores of the Bay of Bengal from Chittagong to the Burma border. Comprehensive field investigations by S. A. Asad and R. G. Schmidt, including airborne radiometric surveys of the entire area, were begun in November 1961 and are continuing. The placers consist of sand generally containing 10 to 30 percent heavy minerals and locally with lenses that contain as much as 96 percent minerals exceeding 2.80 specific gravity (Art. 64).

Field investigations by Habib Abbas and M. G. White of a copper-nodule occurrence in the Central Salt Range reported in the early geological literature on the region resulted in the discovery of apparently extensive copper mineralization. The occurrences are found in the "Speckled sandstone" (late Paleozoic) in the Central and Western Salt Range. To date all localities checked between Nammal gorge to the west and Nilawan gorge to the east contain copper. This presents an inferred strike length of about 65 miles of possible copper-mineralized rock. In general the mineralization as indicated by the presence of malachite and cuprite was weak. One to four beds of weakly mineralized sandstone from a few inches to 6 feet thick in a section as much as 100 feet thick have been found in the upper part of the "Speckled sandstone." Extensive sampling at four widely separated localities has been completed, and laboratory work on the samples is in progress.

A large deposit of barite has been located near Khuzdar, in Kalat Division, West Pakistan. Detailed mapping of the deposit by M. I. Ahmad and F. L. Klinger shows the deposit to be a steeply dipping lens of bedded barite, 1,200 feet long and up to 60 feet thick. It is the largest of a series of similar deposits that follow a zone of strong rock alteration in Jurassic limestone and shale. The structure of the barite deposits is conformable with that of the wallrocks, and although the deposits resemble sedimentary beds they may be of hydrothermal origin. The larger deposit contains at least 500,000 tons of barite. An additional 200,000 tons is probably available from a group of smaller deposits. Most of this tonnage can be mined from opencuts.

Large-scale geologic mapping by Roger van Vloten in the chromite deposits of the Hindubagh mining district has revealed that the chromite ore occurs in the lower part of a layered basic intrusive complex. The lowest exposed part of the intrusive complex is olivine-rich rock, greatly serpentinized. Veins and lenses of chromite seem to occur mainly near the contact with an overlying pyroxenite layer. On top of the pyroxenite a previously unsuspected mass of gabbro was found. The olivine rock is dissected by a diabase dike swarm that does not continue into the gabbro. A large number of faults strike approximately perpendicular to the trend of the dikes, and preliminary results indicate that the chromite veins are parallel to these faults.

Studies by D. H. Dunkle of vertebrate fossils collected by personnel of the Geological Survey of Pakistan have resulted in the recognition of faunal zones in the lower Pleistocene sequence of rocks exposed in the Chandhar anticline, adjacent to the Mangla Dam site near the Kashmir border. Dunkle also found three stratigraphic-paleontologic stages of associated marine invertebrate and continental vertebrate fossils that will be useful to geologists studying middle and upper Tertiary sediments of the lower Indus Basin, east of the axial belt in Kalat, Karachi, and Hyderabad Divisions, West Pakistan.

Hydrologic regimen in the Punjab region, West Pakistan

Detailed geologic and hydrologic investigations were completed in Rechna and Chaj doabs of the Punjab region. Indications are that about 95 percent of a total area of 27 million acres is underlain by saturated alluvium to a depth of 1,000 feet or more. A high-capacity well yielding 5 cubic feet per second or more can be developed at almost any given site. Hydrochemical studies show that the water quality is generally acceptable for irrigation in 80 percent of the area and that the average concentration of dissolved solids is generally less than 1,000 parts per million. The average potential rate of recharge from the existing irrigation system, according to hydrologic studies, may be 0.5 feet of water per year, and the component of recoverable natural recharge may range from 0.2 to 0.3 feet of water per year.

Mineral investigations in Thailand

The cooperative effort in Thailand is directed toward the eventual diversification of the mining industry. Thailand has 200 operating mines of which all except 11 new mines are producing tin and tungsten. The new mines, placed in operation under the present program, produce gypsum, manganese, ceramic materials, coal, and iron ore for local manufacturing. Fluorite is now mined for export. In addition, the first scientific and economic studies of Thailand's tin deposits are now underway. Detailed systematic studies in stratigraphic and structural geology are being carried out for the first time concurrent with these studies in economic geology.

Engineering-geology studies in Indonesia

A detailed geologic study by H. H. Waldron was completed at the Djatiluhur damsite of the Tiitarum River, West Java (Art. 125). The river at the damsite has cut a gorge through a thick sequence of folded marine sedimentary rocks of Tertiary age. The foundation consists principally of a silty shale, with some interbeds of siltstone, fine sandstone, and thin beds and lenses of limestone. A minor anticlinal fold on the south flank of a major anticline underlies part of the damsite. The rock-fill structure will be the first multipurpose dam in Indonesia. When completed, it will be 100 meters high and have a total volume in excess of 10 million cubic meters. Rock-fill is to be derived from nearby masses of intrusive andesitic rock.

Chromite investigations in western Luzon, Zambales Province, Republic of the Philippines

The Zambales mafic complex, exposed over an area 150 miles long and 30 miles wide, has been the subject of study by Darwin Rossman. The rock units are believed to be tabular in shape and to lie one above the other in a succession whose structure is dome shaped—that is, coincidental with the profile of the Zambales Range. The exposed rocks probably are part of a much larger mass. The thickness of the lowest unit, saxonite, is unknown, but the exposed part is probably no more than 5,000 feet thick. The saxonite is overlain by a dunitic zone that ranges from 30 to 1,000 feet in thickness. Gabbro lies over the dunite and has a maximum thickness of 5,000 feet. The bulk of the gabbro is norite, but near the geographic center of the exposed part of the complex the basal part of the gabbro grades into olivine gabbro. The shape of the olivine gabbro is lenticular, and the maximum known thickness is about 1,000 feet.

Diamond drilling on the Zambales Government Reserve has proved 600,000 tons of good refractory grade chromite and twice this amount of probable ore. All known deposits lie below the gabbro in a 1,000-foot-thick zone that includes the dunite and upper part of the saxonite.

Refractory-kaolin deposits, Kinmen (Quemoy) Island, Taiwan

Geologic investigations by Sam Rosenblum on Kinmen (Quemoy) Island, Fukien Province, led to the discovery of at least 65 million metric tons of shallow refractory koalin containing less than 5 percent sand. In addition 30 drill holes indicated several hundred million metric tons of clay containing 5 to 50 percent sand. Iron content for the whole deposit is estimated

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to be from 0.5 to 4.5 percent. The clay and sand layers are apparently recent blankets partly covering a mature granitic gneiss terrane.

Ground-water studies for U.S. Navy at Poro Point, Luzon, Republic of the Philippines

The water supply at Poro Point is obtained from a fresh water lens floating on salt water in limestone and sand. Several tube wells tap this source but the water becomes brackish in May, at the end of the 6-month dry season during which rainfall totals only 4½ inches. Tests and analysis of the data suggest that (a) recharge is derived wholly from precipitation and is about 1,000 to 2,000 acre-feet per year, or between one-third and one-half of the 92 inches of rain that falls from May through October; (b) the amount of ground water stored in the fresh-water lens ranges from about 2,000 acre-feet at the end of the dry season to about 3,500 acre-feet at the end of the wet season; (c) pumpage in 1961 was only about 100 acre-feet; (d) most of the ground water is discharged by natural processes through seeps and submarine springs around Poro Point; and (e) the coefficient of transmissibility is about 200,000 gallons per day per foot, and the coefficient of storage is about 0.13. The field coefficient of permeability may exceed 10,000 gallons per day per square foot.

One shaft well, extending only 3 to 5 feet into the fresh-water lens, obtains potable water the year around. Similar wells, properly spaced along the axis of Poro Point, also could be expected to yield potable water throughout the year. To minimize the possibility of sea-water intrusion, the yield of any single shaft well probably should not exceed 100 gallons per minute. Intermittent pumping causes a surging action in the fresh-water lens and results in a thickening of the transition zone between the fresh and salt water. Thus, to reduce further the threat of sea-water encroachment the wells should be pumped continuously at the minimum rate required to meet the needs for water.

ASTROGEOLOGIC STUDIES

The Geological Survey is continuing its investigations in support of the space exploration program of the National Aeronautics and Space Administration. The emphasis to date has been on research related to problems of the lunar surface. Three main approaches are being followed: geologic mapping of the Moon by means of information obtained from visual, photographic, and photometeric studies with telescopes; investigation of terrestrial and experimental impact and cratering phenomena; and study of extraterrestrial materials that may originate from or occur on the Moon.

PHOTOGEOLOGIC MAPPING OF THE MOON

The earthward face of the Moon is being mapped geologically at a scale of 1:1,000,000. The first maps that have been prepared cover the nominal target area for the Ranger spacecraft of the National Aeronautics and Space Administration. Telescopic photographs are an important source of the information used in mapping, and good progress has been made in assembling a working library of copies of the best available lunar photography.

Lunar stratigraphy

Continued detailed mapping has extended the distribution of the five major stratigraphic divisions of lunar surface rocks recognized in the first detailed mapping (Shoemaker, 1962c). The lunar time scale corresponding to these divisions, which have been termed systems, is as follows:

(Present time)
Copernican Period
Eratosthenian Period
Procellarian Period
Imbrian Period
pre-Imbrian time
(Beginning of lunar history)

Recent work by R. J. Hackman, R. E. Eggleton, and C. H. Marshall has resulted in the establishment of two formal stratigraphic subdivisions of the Imbrian System, which have been named the Apenninian Series and the Archimedian Series (Shoemaker, 1962a). The Apenninian (named for the type area in the lunar Apennine Mountains) comprises a great sheet of material occupying upland areas surrounding the Mare Imbrium Basin. Eggleton and Marshall have found that this unit is more widespread than was recognized earlier; about 80 percent of the earthside hemisphere of the Moon lies within the farthest known limits of the unit. The topographic characteristics of the Apennianian vary with distance from Mare Imbrium. A continuously hummocky facies extends outward 300 to 500 kilometers from the edge of Mare Imbrium. At this distance the hummocky facies grades into a smooth facies with isolated hummocky patches. On the basis of the way the Apenninian fills in older craters, Eggleton has estimated that its thickness in the nominal Ranger target area (selenographic latitude 16° N.–16° S. and selenographic longitude 10°–50° W.) ranges from approximately 500 to 2,000 meters, generally increasing toward Mare Imbrium. These data support the interpretation of the Apenninian Series as an extensive blanket of ejecta derived from the Mare Imbrium Basin.

The Archimedian Series (named for the type area around the crater Archimedes, which is being studied by

Hackman) is composed mainly of the rim materials of craters of post-Apenninian and pre-Procellarian age. The number and size of these craters indicate that the Archimedian Epoch must represent a significant interval of time that intervened between the formation of the Mare Imbrium Basin and its filling by mare material of Procellarian age.

All exposed mare material has been assigned to the Procellarian System, and the major mare areas are apparently of about the same age. Recently, however, Eggleton and Marshall have found numerous restricted areas with marelike topography which are overlain by the Apenninian Series. Pre-Imbrian marelike material presumably occurs in these areas at relatively shallow depth. If the mare material is of volcanic origin, as is generally supposed, the occurrence of pre-Imbrian marelike material suggests that volcanism of the mare type was not restricted to a single episode in the Moon's history.

W. A. Fischer and T. M. Sousa have found that the major stratigraphic units on the Moon may be discriminated by the use of several statistical parameters derived from microdensitometer traverses of full-moon photographs. In further investigations, the data obtained in analog form were converted manually to digital form for preliminary analyses by R. G. Henderson with the use of a high-speed digital computer. Frequency analyses using Fourier transforms, and studies of the autocorrelation function and second derivatives of the densitometer traverses, were carried out. Both frequency and autocorrelation analysis appear promising for use in distinguishing and describing lunar stratigraphic units.

Structural features

E. M. Shoemaker (1962c) compared lunar craters with terrestrial impact craters and maars. Both impact and volcanic craters are probably present on the Moon, and discrimination between the two types by earth-based observations rests chiefly on secondary characteristics of the crater rim material. The characteristics of ray craters, such as Copernicus, match those predicted from a simplified theoretical model of impact cratering. In a further use of the model the expected variation in thickness of the ejecta surrounding an impact crater was derived (Shoemaker, 1961a). The thickness of the ejecta blanket calculated for the crater Copernicus is consistent with observations.

In a study of the distribution of craters of Copernican and Eratosthenian ages, C. H. Marshall has found that the areal density of postmare craters is greater near the center of the lunar disk than near the limb, as would be expected for craters formed by impacting objects traveling in asteroidal orbits, which would be focused by the earth's gravitational field. D. E. Gault, of the National Aeronautics and Space Administration, and C. H. Marshall have restudied the volumetric relations of lunar craters on the basis of topographic data contained in lunar charts prepared by the Air Force Aeronautical Chart and Information Center. They found that the volume of the crater rims is nearly twice the volume of the craters rather than being approximately equivalent, as has been assumed for over a century and a half (Schroeter's Rule).

Although much of the lunar surface may be covered by low-density, possibly noncohesive materials, it is of some interest to consider the thermomechanical effects of the monthly temperature variation that might be expected if rock comparable in strength to ordinary terrestrial rocks were exposed. If such rock responds elastically to the monthly expansion and contraction, surficial tensile stresses an order of magnitude greater than the tensile strength would develop in unfractured rock. On the basis of a recently developed theory, A. H. Lachenbruch (1961a) has found that the resulting tension cracks could be as much as 200 feet deep. At first sight this result is somewhat surprising, as the stresses would be dominated by gravitational compression at depths greater than 15 or 20 feet in unfractured lunar rocks.

The importance of highly instrumented unmanned spacecraft in testing the landing sites and in determining the scientific objectives for the manned lunar exploration was analysed by Shoemaker (1962a). A spacecraft in orbit around the Moon could be instrumented to provide data necessary for detailed geologic mapping of the Moon's surface.

TERRESTRIAL AND EXPERIMENTAL IMPACT AND CRATERING PHENOMENA

The high-speed impact of objects of a great range of size has been a major factor in the development of the Moon's surface, and has played a lesser but appreciable role in the development of the Earth's surface. Accordingly, the Geological Survey is studying both terrestrial meteorite impact craters and experimentally produced impact craters.

Terrestrial craters and structures

A second high-pressure polymorph of silica has been found occurring with coesite in shocked sandstone at Meteor Crater, Ariz. (Chao, Fahey and others, 1962). This mineral has been named stishovite, after S. M. Stishov, who together with S. V. Popova first synthesized this newly discovered phase of silica in 1961 at a pressure of about 110 to 120 kilobars and a temperature of 1,200°C to 1,400°C. Stishovite, in submicron-size grains, forms up to about half a percent of the more strongly shocked sandstone. It is tetragonal with a structure closely related to that of rutile, in which the silicon atoms are in 6-fold rather than the usual 4-fold coordination. The calculated specific gravity is 4.28, much greater than the specific gravity of quartz (2.66) or coesite (2.93). The pressure at which stishovite was synthesized is equivalent to that at a depth of about 400 kilometers in the earth; its presence at Meteor Crater is attributed to the transient shock pressure accompanying meteorite impact.

Small amounts of coesite have been found by Janet Littler, J. J. Fahey, and D. J. Milton in glassy ejecta collected by E. M. Shoemaker from the Scooter Crater produced by the underground explosion of 500 tons of TNT in alluvium at the Nevada Test Site. The peak pressure to which this material was subjected was calculated to be close to 150 kilobars.

Thermoluminescence of the rocks exposed in the rim of Meteor Crater, Ariz., has been found by C. H. Roach, G. R. Johnson, J. G. McGrath, and T. S. Sterrett (Art. 149) to have been markedly affected by the shock produced by impact. Thermoluminescence characteristics of samples taken from three separate beds at various points along the crater rim indicate that the southeast quadrant of the crater rim received stronger shock than the northern part of the rim. Rocks at a greater depth in the southeast part of the crater wall also appear to have been more strongly shocked than elsewhere. Bulk density of rocks from a given bed tends to vary directly with inferred shock strength. The observed relations suggest that the point of entry of the meteorite into the ground may have been closer to the southeast quadrant than to other points on the crater rim, as would be expected if the meteorite were moving from a southerly or southeasterly direction toward the north or northwest.

On a reconnaissance trip to the New Quebec Crater, Quebec, under the auspices of the Dominion Observatory of Canada, E. M. Shoemaker found that sheeting in the crystalline rocks in which the crater is formed is turned up sharply where the bedrock is exposed near the crest of the crater rim. The structure is in this way analogous to that at Meteor Crater, Ariz. Rocks ejected from the crater apparently have been preserved locally on the crest of the eastern rim and possibly elsewhere on the outer flanks of the rim.

At Kofels, in the Tyrolean Alps of Austria, a craterlike hanging valley in an area of intensely fractured rock is blocked by several cubic miles of rubble, at the edge of which is a dike of vesicular glass. The dike has been attributed to vulcanism of late Quaternary age by most Austrian geologists, but an impact origin has also been suggested for the valley and associated features. The dike rock was studied by D. J. Milton and features were found, notably the melting of quartz grains without solution in the matrix glass, that do not occur in volcanic products but are found at larger meteorite craters. Comparison with the Neptune nuclear crater on a steep slope in the Nevada Test Site suggests that some unusual structural features of the Kofels area may in part be caused by meteorite impact on a steep mountain side.

E. M. Shoemaker and R. E. Eggleton have found that Cretaceous rocks at the Sierra Madera disturbance, Texas, were intensely deformed together with Permian rocks. This leads to a simplification of the structural history over previous interpretations. Detailed mapping in a radial sector of the roughly circular structure shows outward overthrusting and overturned and asymmetrical folding diminishing in intensity outward. Reconnaissance suggests that similar relations hold in other sectors around the structure. Both the inferred single period of intense disturbance and the character of the deformation are consistent with an impact origin of the structure.

Experimental cratering phenomena

An experimental study of cratering by impact of hypervelocity projectiles in rock is being carried out jointly by the Geological Survey and the Ames Research Center of the National Aeronautics and Space Administration. Investigation of the characteristics of particles ejected from the craters formed by impact led to the development by E. M. Shoemaker, D. E. Gault,[49] and H. J. Moore of a mathematical model in closed analytical form for the production of lunar particles by impact of interplanetary particles. On the basis of estimates of the velocity, space density, and mass distribution of the interplanetary particles, the flux of lunar particles at the lunar surface was found to be sufficiently great to warrant investigation. This will be attempted by means of instruments placed on the spacecraft being designed for soft landing on the lunar surface under the Surveyor project of the National Aeronautics and Space Administration. Both the television system on the Surveyor spacecraft and the acoustical detectors were recommended for this purpose. Investigation of the flux is of considerable importance to the national space program because it appears to constitute a possibly severe hazard not only to exposed optical surfaces but also to men placed on the Moon.

Faint clouds reportedly observed by K. Kordylewski in the Earth-Moon triangular-libration regions were suggested by Shoemaker (1962b) to be composed of

[49] Ames Research Center, National Aeronautics and Space Administration.

particles ejected at escape velocity from the Moon. A program for studying and sampling these clouds was suggested and a photographic investigation to confirm their existence has been initiated by E. C. Morris and H. G. Stephens. On the basis of the experimental-cratering data, an estimate of the possibilities of telescopic observation of the nonluminous ejecta that will be produced by the impact of the Ranger spacecraft was prepared by Shoemaker and Moore. It was concluded that there was a reasonable but marginal chance that the event could be observed from Earth-based telescopes.

EXTRATERRESTRIAL MATERIALS

In 1962, work on extraterrestrial materials was largely restricted to tektites. Evidence is accumulating to indicate that tektites are the product of large-scale impacts (Choa, Adler, and others, 1962), and the probability is good that the impacts occurred on the Moon. Current work is chiefly directed toward systematic studies of the chemical composition, petrography, and physical properties of tektites from the known major strewn fields.

Support for the impact origin of tektites was obtained from petrographic study of material from a large crater of probable impact origin (Shoemaker and Chao, 1961). In the Otting quarry at the Ries Crater, Germany, Chao found small amounts of a dense impactite glass intermediate in petrographic characteristics between typical impactite glass and tektites. The glass contains inclusions of lechatelierite and shows flow structures similar to those of tektites. Its magnetic susceptibility, measured by F. E. Senftle, is 6.62×10^{-6} emu per g, similar to that of some indochinites and philippinites. The glass, however, contains crystal fragments, which are not found in tektites.

As a part of a systematic investigation of the chemistry of tektites, a method was developed by M. K. Carron and Frank Cuttitta (Art. 30) for accurate determination of silica in small samples of tektites by volatilization (see also p. A117. The method is applicable to tektites because of their very low content of volatile constituents.

The major and minor chemical constituents of 21 selected Texas tektites (bediasites) and 4 Philippine tektites (philippinites) have been determined by a monitored system of high-precision methods by Frank Cuttitta, M. K. Carron, and Janet Fletcher. Alumina, ferrous iron, and titania increase with increasing index of refraction and magnetic susceptibility and decrease with increasing silica content. The silica content of the bediasites ranges from 71 to 81 percent. The chemical evidence suggests that all the tektites of Texas belong to a single shower. Ferric-ferrous ratios of the analyzed bediasites are much less than those found in fused terrestrial rocks. This suggests that tektites were fused in an environment where the partial pressure of oxygen was many orders of magnitude less than that on the surface of our planet.

The composition of bediasites may be compared with that of terrestrial rocks by recalculating the chemical analyses on a water-free basis with respect to a standard rock cell containing 160 oxygen atoms. Differences in composition shown in terms of "gain" and "loss" necessary to make a pre-existing rock into a tektite can then be compared with the chemical changes that might be expected as a result of fractional volatilization. Bediasites are more similar to rhyolitic igneous rocks than to graywacke sandstones, with which they had been compared previously. Meteorite impact on an extraterrestrial body with widespread rocks of rhyolitic composition should be considered as a likely origin of tektites.

Complete physical and chemical data for a single tektite discovered on Martha's Vineyard, Mass.,[50] and one of the rare tektites from Georgia were obtained in a joint study with the U. S. National Museum (Clarke and Carron, 1961). The two objects are closely similar to the most siliceous bediasites from Texas.

New measurements of the magnetic susceptibilities of australites, bediasites, and philippinites by F. E. Senftle, A. N. Thorpe, and Alfred Hoyt, extend the known range for each group. The susceptibilities, which range from 4.00×10^{-6} to 8.60×10^{-6} emu per g, correlate well with the FeO content. Electrical conductivities of tektites, measured between 100°C and 150°C and corrected to room temperature, show a range from 9.34×10^{-16} to 2.56×10^{-13} ohm^{-1} cm^{-1}. The thermal conductivity of a philippinite was measured by E. C. Robertson as 2.79×10^{-3} cal per cm sec deg C, near that of other silicate glasses.

INVESTIGATIONS OF GEOLOGIC AND HYDROLOGIC PROCESSES AND PRINCIPLES

Although the following discussion of investigations of fundamental processes and principles in various phases of geology and hydrology is presented separately from sections on resource investigations and regional studies, all these studies are closely interrelated in the overall program of the Geological Survey. Coordination of applied and theoretical work is maintained so that each contributes significantly to the other. Owing to this interrelation of activities, it is difficult to separate clearly the results of the topical studies from those of a more regional nature. Thus, the reader may find addi-

[50] Kaye, C. A., Schnetzler, C. C., and Chase, J. N., 1961, A tektite from Gay Head, Martha's Vineyard, Massachusetts: Geol. Soc. America Bull., v. 72, no. 2, p. 339–340.

tional topical studies as applied to specific geographic areas reported in preceeding sections.

PALEONTOLOGY

Paleontologic studies bearing mainly upon regional problems are discussed in other sections of this review. Reported here are findings which have to do with evolution, paleoecology, morphology and systematic paleontology, and stratigraphic paleontology.

Evolution

Findings of Geological Survey paleontologists during 1962 shed new light on the evolution and migration of whales and mollusks.

A 50-foot whalebone whale, excavated jointly by F. C. Whitmore, Jr., of the Geological Survey, and paleontologists of the Smithsonian Institution, reveals advanced evolutionary features not previously recorded among Miocene Cetacea. The new form, recovered from the upper Miocene Yorktown Formation at Hampton, Va., has cervical vertebrae that are fused together; the skull rostrum has the bow-shaped profile of a modern baleen whale. Although the genus *Balaena*, to which the Yorktown Miocene specimen is related, occurs in the European Pliocene, it has not previously been reported below the Pleistocene in the western hemisphere. The well-known middle Miocene cetotheres of the Calvert Formation in Maryland are a more primitive group ancestral to whalebone whales; these cetotheres are much smaller than the Yorktown specimen, lack the bow-shaped skull profile, and have separate rather than fused neck vertebrae. If the Yorktown upper Miocene whalebone whales evolved from the Calvert middle Miocene cetotheres, evolution must have been rapid. More tenable, perhaps, is a theory that the balaenids developed elsewhere in the world during early Miocene or even earlier Cenozoic time, and were contemporaneous with primitive cetotheres.

The gastropod *Neptunea* is indigenous to the Pacific Ocean. F. S. MacNeil's studies of evolution and migration of this genus in Alaska and regions adjoining the North Pacific indicate its earliest occurrence in lower Cenozoic rocks of East Asia. By Oligocene time, *Neptunea* was present in Alaska, thence migrating southward in the Miocene. Other *Neptunea* stocks spread through the Arctic regions during the Pliocene and Pleistocene, reaching Europe in preglacial Pleistocene time. A *Neptunea* stock populated the North Atlantic coast of America in the late Pleistocene. The Arctic dispersal pattern of this differentiating Pacific gastropod may apply as well to other Cenozoic organisms which reached Atlantic waters relatively late.

Detailed evolutionary studies of Gulf coast Upper Cretaceous gastropods by N. F. Sohl seem to indicate that the large molluscan fauna of the *Exogyra costata* zone (Campanian-Maestrichtian) did not arise by sudden invasion of new types, but was the product of evolutionary development from lineages already well established in the Gulf coast region as early as Coniacian.

Paleoecology

W. J. Sando's investigations of Madison Lower Mississippian corals from wells in the Williston basin of North Dakota give evidence of biologic response of bottom faunas to changing ecologic conditions. Coral impoverishment in the Lodgepole Limestone toward the north is apparently related to increased clay content and decreasing grain size of limestone as the basin center is approached; in that vicinity, water circulation is believed to have been poor. Coral faunas of the overlying Mission Canyon Limestone, however, are distributed more uniformly, suggesting well-aerated bottoms. In late Madison time (Charles Formation) the coral distribution pattern again shifted in response to northward increase of evaporites and restriction of the sea.

Fossil bison and mammoth bones associated with human artifacts were collected at the Lamb site southwest of Littleton, Colo., by G. E. Lewis, with C. L. Gazin and Waldo Wedel, U.S. National Museum. These finds confirm Lewis' earlier interpretation of the site as a late Wisconsin bog containing a stratigraphic succession of late Pleistocene faunas.

Six floral zones have been recognized by J. A. Wolfe (Art. 89) in a sequence of volcanic rocks from the Cascade Mountains in northern Oregon. These rocks, representing much of the Miocene Series, contain both leaves and plant microfossils. The pollen and spores indicate the gradual replacement of a broad-leafed forest by a coniferous forest during the Miocene; by latest Miocene time this coniferous forest was the dominant vegetation in the Cascade Range.

A remarkable concentration of Permian amphibian remains was discovered in north Texas by S. H. Mamay. This occurrence, associated with fossil plants in the Vale Formation, has produced approximately 300 skulls. It constitutes the richest Permian vertebrate deposit of its kind yet found in North America. The fauna, consisting of several species, evidently was concentrated in the waters of a drying pond, where the animals expired because of their inability to walk on land.

Morphology and systematic paleontology

R. E. Grant has described unusual and previously unknown attachment structures of *Linoproductus augustus* King. This study of brachiopod structure is a byproduct of Grant's comprehensive systematic work on Texas Permian brachiopods carried out jointly with

G. A. Cooper of the Smithsonian Institution. Unlike many productids, this linoproductid species developed spines solely along the cardinal margin. The spines grew in opposing pairs, locking the brachiopod permanently in suspended attachment to a crinoid column or other cylindrical object.

In systematic studies of upper Paleozoic ostracodes, I. G. Sohn has revised classification of a stratigraphically useful group, including *Aechminella*, *Amphissites*, and related genera, providing range charts and identification keys to species and genera.

Collections of Permian plants were made by S. H. Mamay fom the Admiral and Vale Formations at several north Texas localities. Plants from the Admiral, the first obtained from this formation, fill an important gap in the sequence of Permian floras known in North America. The plants in the Vale include new forms of *Gigantopteris* that contribute significantly to understanding this botanical complex.

Stratigraphic paleontology

J. M. Berdan's studies of lower Paleozoic ostracodes from Nevada suggest that at least three stratigraphically useful assemblages are present in the Silurian and Devonian. One, characterized by *Mesomphalus*, is probably Late Silurian, but possibly is Early Devonian in age. Another assemblage, characterized by *Thlipsura*, appears to be Early Devonian, and in several collections is associated with brachiopods referable to *Leptocoelia*. The third assemblage, characterized by *Hanaites* and other hollinid genera, is Middle Devonian.

Compound rugose corals of the Onondaga Limestone in New York, described by W. A. Oliver, Jr., support a Middle Devonian age. These corals are locally concentrated, being most abundant in reef facies, common in biostrome facies, but rare in the greater part of this extensive limestone unit.

Correlation of American stratal units with those of the Old World is always significant. New vertebrate evidence regarding correlation of the Cutler Formation in Colorado with Permian rocks of France and Germany is brought forth by discovery of a new pelycosaur in the Cutler. The Cutler haptodontine pelycosaur, as described by G. E. Lewis and P. P. Vaughn, is closely related to *Haptodus* of the Autunian in France and the Rothliegende of Germany.

Studies by R. W. Imlay of ammonites from the John Day region, eastern Oregon, demonstrate that Early Jurassic strata previously regarded as Upper Triassic in that region were incorrectly assigned. Middle and Late Jurassic ammonites from the Bedford Canyon Formation, Santa Anna Mountains, Calif., have been shown by Imlay to be related to European Tethyan species, and are without affinity to ammonites of corresponding age in higher latitudes of northern California, Oregon, and Alaska. Early and Middle Jurassic ammonites were collected by Imlay in the Sailor Canyon Formation of the Sierra Nevada, Calif.

W. A. Cobban has been able to subdivide Cretaceous rocks in the lower part of the Montana Group (Art. 22) on the basis of ammonites. The *Scaphites hippocrepis* Range Zone now can be subdivided into an early subzone characterized by *Haresiceras montanense* (Reeside), a middle subzone marked by *Haresiceras placentiforme* Reeside, and a late subzone that has as its guide fossil *Haresiceras natronense* Reeside.

The value of the Oligocene as a worldwide geologic series has frequently been questioned, particularly in North America where this subdivision is poorly understood. F. S. MacNeil's researches upon the Vicksburg mollusk faunas of Mississippi are therefore of significance. MacNeil recognizes a very close genetic relation between upper Eocene and Oligocene molluscan faunas of Europe and those of the Gulf coast, wherein the Mint Spring Marl Member of the Marianna Limestone correlates with the European Rupelien. Vague similarities also exist between the Vicksburg faunas and those of the Peruvian Oligocene, although both may be descendants of stocks isolated since Eocene. MacNeil's studies reveal no close relation between Vicksburg Oligocene mollusks and those of western North America.

Studies by Ruth Todd of planktonic Foraminifera in deep-sea cores from a guyot adjoining Eniwetok Atoll in the Marshall Islands suggest that certain species may be useful in establishing ages from late Miocene to Recent. *Globoquadrina altispira* (Cushman and Jarvis) is indicative of late Miocene age. *Globigerinoides sacculifer fistulosa* (Schubert), in the absence of the Recent species *Globorotalia truncatulinoides* (d'Orbigny), is indicative of early Pliocene age. Approximate correlation of late Miocene sections is possible between the central Pacific, the West Indies, the Mediterranean region, and Australia.

GEOMORPHOLOGY

Studies of ancient and modern landforms are important in helping to reconstruct geologic and hydrologic history. Consideration of landforms and the processes involved in their development may also have practical applications in problems such as groundwater supplies, construction engineering, erosion, and radioactive-waste disposal. Results of some studies in geomorphology involved in these problems and others are discussed in this section. Studies of a more regional nature are summarized under regional headings elsewhere in this chapter.

Morphology of stream channels

Study of the channel geometry of a small tidal channel by R. M. Myrick, L. B. Leopold, and W. B. Langbein yielded data on the down-channel change of width, depth, and velocity with discharge as discharge changes through a tidal cycle. The field measurements agreed closely with a theoretical development based on the concept that such a channel system tends toward a uniform distribution of energy and a minimum rate of work in the system as a whole.

Landforms of the Lebanon Valley (part of the Great Valley in southeastern Pennsylvania) are interpreted by H. Meisler to be the result of erosion within two separate stream systems—Swatara Creek and the ancestral Quittapahilla Creek—in which streams and interfluvial areas were in a state of erosional equilibrium. The land surface in equilibrium with the ancestral Quittapahilla Creek is at a higher elevation than adjacent land surfaces that were in equilibrium with Swatara Creek. Accordance of summits is the result of uniform erosion of uniform rocks in basins whose discharge points are at the same elevation. Lack of accordant summits on uniform rocks is the result of erosion in basins whose discharge points differ in elevation.

Geomorphology related to ground water

H. E. LeGrand (1962a) states that a careful examination and evaluation of landforms can solve many problems concerning ground-water supply, disposal of radioactive wastes, and engineering geology. For example, in the Atlantic and Gulf Coastal Plains an effect of stream entrenchment is the steepening of the hydraulic gradient and the consequent increase in the rate of flow in valleys where ground water discharges (LeGrand, 1962b). He states that the ground-water discharge and the base flow of streams in the coastal plain is derived from the water table and, locally, the uppermost artesian aquifer.

L. A. Heindl (Art. 109) demonstrates that the heterogeneity of alluvial deposits is not necessarily random along the Santa Cruz River south of Tucson, Ariz. He points out that ground-water shadows, areas of low yield bounded either by areas of higher yield or by nearly impermeable rocks, reflect the influence of the depositional environment on local ground-water conditions. Better sorted and more permeable materials are deposited in the central parts of valleys where trunk streamflow is concentrated, whereas the less permeable materials are deposited adjacent to ridges by less competent streams. Ground-water shadows also occur beneath buried ridges and valleys.

During evaluation of the Queen Lake depression in Eddy County, N. Mex., as a storage basin for brine, E. R. Cox and J. S. Havens found that the depression probably was formed during late Quaternary time by solution and collapse of rocks in the lower part of the Rustler Formation of Permian age. The depression was partly filled by alluvium derived from nearby material. Collapse breccia beneath the depression extends downward almost to the top of the salt of the Salado Formation.

Geomorphology and geology in relation to streamflow

Studies in northern Arizona and southern Utah by M. E. Cooley (Art. 18) show that tributaries of the Colorado River in this area cut their channels as much as 800 to 1,500 feet deeper during Quaternary time. Five cycles of downcutting and alluviation occurred in Pleistocene. Two prominent and two secondary erosion cycles occurred in Recent time. He recognizes 5 Recent alluvial units, dating from before A.D. 500 to the present based on cultural materials, and he believes that the lowest 2 of these units, units 4 and 5, are roughly correlative with the Tsegi Formation [51] of Jeddito Valley. The first prominent erosion cycle of Recent time, from A.D. 1100 to A.D. 1400, terminated deposition of unit 4. Deposition of unit 3, which is probably correlative with the Naha Formation,[51] followed. Events associated with the present episode of arroyo cutting, which started about A.D. 1850, abruptly terminated deposition of unit 3. Units 1 and 2 have been deposited during this last period of arroyo cutting.

W. J. Schneider, in a study of two areas in Georgia (Art. 47), has found that streams there become perennial at the beginnings of incised stream channels. Each of the areas is a sample of a physiographic province of Georgia, one in the Coastal Plain and the other in the Piedmont. He noted that first- and second-order streams in the Piedmont have convex profiles if perennial and concave profiles if ephemeral.

In an investigation of the relation of geology of the base runoff of streams in an area of 134 square miles in the Piedmont of Georgia, O. J. Cosner reports that streams having highest base runoff are in an area of low, rounded hills underlain by biotite gneiss and hornblende gneiss. The effect of geology on base runoff, however, is masked by evapotranspiration, which accounts for about two-thirds of the annual precipitation. Areas with the highest base runoff also have the least evapotranspiration. Small basins of the Piedmont generally have two aquifers: a ridge-section aquifer and a flood-plain aquifer. Water-table contours in the flood-plain aquifer are parallel to the stream and show that water moves across this aquifer from the ridge

[51] Hack, J. T., 1941, Dunes of the western Navajo Country: Geog. Rev., v. 31, no. 2, p. 262–263.

section to the stream. Underflow parallel to the stream is practically nil in the flood-plain aquifer.

According to F. A. Kilpatrick, who is making a detailed study of the source of base runoff in a 1-square mile basin in the Piedmont of Georgia, transmissibilities range from less than 100 to nearly 1,000 gallons per day per foot in both the ridge-section and the flood-plain aquifers. Tests completed to date indicate leaky artesian conditions in both aquifers.

In the parts of the Black Earth Creek basin, Wisconsin, covered by glacial drift, the ground-water discharge to streams was found by D. R. Cline to be significantly higher than in the driftless areas.

Morphology of alluvial fans

Alluvial-fan sizes, slopes, and shapes reflect the erosional and tectonic histories of their drainage basins. Studies in western Fresno County, Calif., by W. B. Bull (Art. 19) show that fan morphology in this area is affected by such factors as drainage-basin size, lithology, and uplift. Fans derived from mudstone- or shale-rich drainage basins are steeper than fans of similar area that are derived from sandstone-rich basins, and are roughly twice as large as the fans derived from sandstone-rich basins of comparable size. Studies of topographic profiles show that intermittent uplift of the mountains in western Fresno County has steepened the stream gradients and has caused most fan deposits to accumulate at steeper slopes than before uplift. The resulting fans have radial profiles that are segmented.

PLANT ECOLOGY

A knowledge of the distribution of plants and development of the present vegetation is necessary to a full understanding of geomorphic and hydrologic processes because past climatic trends can be reconstructed from analyses of the present vegetation.

Relation of vegetation to soil moisture

As part of the continuing program to investigate the relations between plant communities and soil moisture in the semi-arid West, F. A. Branson and R. S. Aro are studying vegetation in connection with various types of land treatment. In a project designed to determine the effects of eradication of juniper and pinyon in parts of Arizona, they found at Apache Pond near Show Low that the herbaceous vegetation has increased in density since the trees were removed.

A 10-year study of the effect of contour furrowing, grazing intensity, and soil on range vegetation near Fort Peck, Mont., shows that almost no increase in vegetation resulted from different treatments of poor soils having a sodium-dispersed zone near the surface (Branson, Miller, and McQueen, 1962). On the better soils, however, furrowing resulted in the establishment of a satisfactory stand of desert wheatgrass following seeding. Heavy grazing caused a marked reduction in the yield of all herbaceous plants, as well as desert wheatgrass, during a dry year but only a slight reduction in yield during a moist year.

Forests and geomorphology

Studies by J. C. Goodlett and W. J. Schneider in the Yellow River drainage basin of the Piedmont region of Georgia show that the highly variable wild vegetation can be described in terms of differences in bedrock, soils, the size of the valley, the shape of the valley profile, and topographic form. Forests on crests and ridges contain many tree species absent from valley floors of higher order streams. Forests in first-order valleys contain most of the tree species that grow on crests and on floors of higher order valleys but show pronounced changes in composition from their heads to mouths. These changes presumably reflect adjustments within the plant cover to differences in the present environments within the valleys and chiefly to differences in moisture regimes. The presence of pure stands of pine trees, however, is most closely related to past use of the land rather than to physical characteristics of the environment.

Effects of coal strip mining upon forests

As part of a project to determine the hydrologic and related effects of coal strip mining in eastern Kentucky, R. S. Sigafoos (*in* Collier, 1962) has studied the effect of acid drainage from the mined area upon the growth of trees in the surrounding forest. Results show that trees irrigated by the drainage are growing faster than they did before mining and faster than those not irrigated by the drainage. The high concentrations of mineral matter in the drainage are believed to be the cause of the increased growth.

Trees as indicators of floods

In a continuing study of botanical evidence of floods, R. S. Sigafoos has found evidence of every high flow since the maximum flood of record on March 19, 1936, along one short reach of the Potomac River near Washington, D.C. Some evidence of the 1924, 1889, and 1861 floods also has been found. This consists of the age of sprouts from inclined trunks and scars in cross sections of stems. Preliminary results indicate that boxelder and silver maple trees grow only on fine-grained alluvium on flood plains, whereas shingle, swamp white, and swamp chestnut oaks grow only on bedrock surfaces that are flooded as frequently as the flood plains.

GLACIOLOGY AND GLACIAL GEOLOGY

About 10 percent of the earth's surface is now covered by perennial icefields and snowfields. During past geologic epochs glacial activity involved much larger areas, including a large part of the United States. Studies of glaciers and glacial deposits are important not only for their purely scientific value but also in their application to many problems in water resources, agriculture, mining, and construction engineering.

Studies of existing glaciers

Detailed studies of the regimen of South Cascade Glacier, Wash., by M. F. Meier and W. V. Tangborn showed the unusual character of the glacier budget in 1960–61. Because of deficient snow at low altitudes and a prolonged ablation season, the specific net budget for the glacier averaged about −44 inches of water, but reached −293 inches of water near the terminus. This is the largest net deficit at low elevations ever measured on this glacier. Surface elevation changes and ablation studies on Nisqually and other glaciers showed similar results.

A recent result of the South Cascade Glacier work was the discovery that the accumulation-area ratio is directly related to the average glacier net budget. This hypothesis was applied by M. F. Meier and A. S. Post to derive information on the net budget of many hundreds of glaciers in northwest North America by using simple aerial-reconnaissance photography. The results showed that glacier net budgets during 1960–61 were generally positive only in the Coast Range from southeastern Alaska to British Columbia, and that glacier net budgets were generally negative away from this area.

Analysis of the glacial regime in Greenland north of lat 76° N. by W. E. Davis and D. B. Krinsley indicates that below an altitude of 3,000 feet, melt greatly exceeds snow deposition and ice flow from adjacent icecaps. In this zone, glaciers are now in retreat. Glaciers that terminate on land have retreated from 100 to more than 1,500 feet from their end moraines of 1892–1900. Glaciers afloat have retreated from several hundred feet to more than 2,000 feet. The maximum position of glaciers afloat was reached in the early 1920's. The present retreat is counter to observations on the icecap above an altitude of 3,000 feet, where there is a net balance of snow accumulation.

Glacier hydrology

Water-budget data were obtained by M. F. Meier and W. V. Tangborn from the South Cascade Glacier basin, Washington. For the part of the basin that contains the glacier, runoff was about 200 inches and precipitation only 156 inches during the 1960–61 budget year; the difference of 44 inches was due to withdrawal of water from ice storage because of the abnormal melt.

A small drainage basin that does not contain a glacier adjacent to and having approximately the same area-altitude distribution as the South Cascade Glacier basin was studied by W. V. Tangborn. He showed that this basin's yearly hydrograph was strikingly different from the hydrograph of the South Cascade Glacier basin: storm-runoff timing was different, runoff was more directly related to precipitation, and water losses were more noticeable in the basin not covered by a glacier.

Glacial geology

Fieldwork and analytical studies of so-called tillites of pre-Pleistocene age in North America, and a review of published descriptions of the pre-Pleistocene tillites of Africa, Australia, India, Russia, South America, and Tasmania by A. E. J. Engel and C. G. Engel indicate that these rocks are largely graywackes, argillites, and graywacke conglomerates. Most of these rocks appear to be products of debris and turbidity flows and mudslides, commonly associated with subareal and submarine vulcanism. Hence, these "tillites" must be reexamined to evaluate whether glaciers are involved either directly, or incidentally, in the rock-forming process. Conclusions from these studies may suggest important modifications in existing concepts of the secular variations in climates.

Recent exposures of the internal structure of end moraines in Ohio have shown them to be made up of several discrete till sheets, according to studies by G. W. White (Art. 95). Apparently the moraines themselves may have limited the spread of the ice, and they antedate the last ice advance.

T. L. Péwé and L. Burbank, in an analysis of the glacial features of the Yukon-Tanana upland in central Alaska, find at least two glaciations of the upland by small alpine-type glaciers. The area has no glaciers today. The orientation of 1,088 cirques was plotted, and it was found that most of the cirques face in a direction between north and N. 20° E.

The extensive deposits of loess in Alaska range in thickness from a film to more than 200 feet at Fairbanks, according to a compilation of data by T. L. Péwé. The deposits in Alaska are as thick as those reported elsewhere in the United States and are among the largest in area. The loess is mainly confined to lowlands bordering the major rivers, all of which drained extensively glaciated areas in the past. In addition to the Quaternary loess, windblown dust is currently being deposited in many areas.

Drift sheets of three alpine glaciations of Wisconsin (post-Sangamon) age and at least one of pre-Wisconsin age have been found by D. R. Crandell and R. D. Miller along the Nisqually River valley between Mount

Rainier and the Puget Sound lowland in western Washington. Differences in weathering features in the drifts support assignments to three separate glaciations in Wisconsin time. The two older glaciers of Wisconsin age formed icecaps on part of the Cascade Range, but during the most recent glaciation a valley glacier headed in cirques in the Cascades and on Mount Rainier.

D. R. Crandell found evidence of three glaciations of the southwestern part of the Olympic Peninsula, Wash., in Wisconsin (post-Sangamon) time. During the first two glaciations, piedmont lobes heading in icecaps in the Olympic Mountains reached to within a few miles of the Pacific Ocean, and a lobe from the Hoh River valley probably extended westward beyond the present shoreline. During the last glaciation of Wisconsin time, glaciers were much smaller and few even reached the southwest front of the Olympic Mountains.

D. V. Harris and R. K. Fahnestock have restudied the lower Pleistocene Prairie Divide Till [52] in Colorado and conclude that it was emplaced by an icecap glacier moving from the Cameron Pass area (35 miles away) over topography radically different from that of the present (Art. 17).

OCEANOGRAPHY AND MARINE GEOLOGY

Investigations by the Geological Survey related to oceanography and marine geology continue to increase and to be characterized by the diversity of subjects and geographic areas investigated, and by the close collaboration with other organizations, notably the Coast and Geodetic Survey, the Navy Hydrographic Office, the Atomic Energy Commission, and the Coast Guard.

National ocean-survey program

During fiscal year 1962, five Geological Survey scientists were abroad the Coast and Geodetic Survey ship *Pioneer* during several cruises in the North Pacific. These were the first operations in a long-range national and international program to make systematic observations of broad oceanic areas and eventually to produce detailed scientific maps and charts of the entire world ocean. Geochemical studies of bottom sediments and ocean water by G. W. Moore and C. E. Roberson, of the Geological Survey, and H. D. Nygren, of the Coast and Geodetic Survey (Art. 33), showed that the carbon dioxide content of the sediments is relatively constant and is not a function of latitude. Deep-sea manganese nodules were collected from eight widely separated localities and all proved to be composed of the mineral todorokite. Gravity observations made cooperatively by the Coast and Geodetic Survey on the ship and the Geological Survey along the Alaska Peninsula shoreline indicate that a gravity low associated with Kodiak Island broadens and deepens southwest of the island. There is no indication in the Shelikof Strait area of the pronounced gravity low associated with the Cook Inlet geosyncline. Atmospheric aerosol and rainwater samples were taken in plastic-lined collectors mounted on the flying bridge, and will be chemically and radiologically analyzed.

Analysis of preliminary Mohole samples, Guadalupe site

A number of Geological Survey scientists have been studying samples from the preliminary drilling phase of the Mohole project under the coordination of H. S. Ladd and J. R. Balsley, Cochairmen of the Panel on Scientific Objectives and Measurements of the AMSOC Committee of the National Academy of Sciences. The coring operations near Guadalupe Island and the cores recovered in deep water have been described by Riedel, Ladd, Tracey, and Bramlette (1961). The chemical composition, CIPW norm, and approximate mode of a basalt sample from about 565 feet below the ocean bottom have been determined by C. G. Engel and A. E. J. Engel (1961). The mode in volume percent as based on 500 counts is augite 49, plagioclase 41, olivine 1, opaque minerals 5, calcite 1, and chlorite, serpentine, palagonite, and zeolite, total of 3.

Other Geological Survey work being done on samples from the Guadalupe site includes isotopic investigations of dolomite and interstitial waters by Irving Friedman, and magnetic measurements by George Keller and Charles Zablocki, and by A. V. Cox and R. R. Doell. Chemical work on samples is being coordinated by K. J. Murata, complete chemical analyses of sediment samples are being made by Leonard Shapiro, and clay mineralogy and ion-exchange characteristics are being determined by Dorothy Carroll. Microfossils from the sediment cores included a few ostracodes, which have been studied by I. G. Sohn.

Marine geology

Radiocarbon dates determined by Meyer Rubin from the sloping base of salt-marsh peat in an excavation for an underground garage in the Boston Common, combined with dates of samples from other Boston localities, indicate that the postglacial sea-level rise reached to within 3 feet of the present datum about 2,500 years ago. As part of this study C. A. Kaye has noted that the compression of peat under its own weight is considerable and must be taken into account by a compression factor when referring radiocarbon dates of marsh peat to former sea levels.

Another study by Kaye shows that the present sea-level rise recorded by tide gages probably dates back no further than the late 19th century. Comparison

[52] Bryan, Kirk, and Ray, L. L., 1940, Geologic antiquity of the Lindenmeier site in Colorado: Smithsonian Misc. Coll., v. 99, no. 2, 76 p.

of 19th-century and modern levels of the intertidal barnacle zone has indicated that the present rise of sea level is greater than the barnacle-zone rise rate of about 3 inches in 80 years. The lag of the barnacle zone is the result of a sea-level stillstand during at least much of the 19th century.

Organic material (USGS Lab. No. W-945) collected by J. E. Upson and C. W. Spencer from cores for bridge borings for the Connecticut Turnpike across the Quinnipiac River at New Haven has a radiocarbon age of 5,900 ± 200 years B.P. according to determination by Meyer Rubin. The material came from a depth of 30 to 31.5 feet below mean sea level, and suggests a relative rise of sea level of roughly that amount in the past 6,000 years. Pollen from this sample and from other samples at about the same depth, analyzed at the Denver laboratory of the Geological Survey and reported by E. B. Leopold, probably falls in the B or C-1 pollen zone of Deevey.[53] A sample of peat (USGS Lab. No. W-1082) collected from 13.6 feet below mean sea level at Mystic Harbor, Conn., was determined to be 2,850±260 years old. The two points help define a curve of relative sea-level rise that generally agrees with other sea-level curves for southern New England.

Intraformational recumbent folding, a common feature of the Nubian sandstone of North Africa, Shinarump Member of the Chinle Formation, and other sandstones, has been reproduced in the Denver sedimentation laboratory of E. D. McKee by forcing sand masses of flood action across a set of submerged foresets (Arts. 164, 165). Basic differences between these structures and such others as convolute bedding and contorted bedding have thus been clarified.

Marine geophysics

A study of Arctic aeromagnetic data was conducted jointly with the Coast and Geodetic Survey has yielded a wealth of information on 1,350,000 square miles of Arctic Ocean in the Western Hemisphere between the North Pole and the North American continent. Examination of 23,000 miles of aeromagnetic profiles by E. R. King has shown that most of the high-amplitude anomalies are in a single large area west of the 90° meridian. The edge of this zone is especially sharp where it crosses the continental shelf off the Canadian Archipelago, suggesting faulted margins. Faults may also be an important factor within the zone, particularly along the flanks of the Alpha Rise. The presence of large negative anomalies, and the great size of the anomalies characteristic of this zone, indicate rocks with strong remanent magnetization typical of many volcanic areas. The persistent magnetic anomaly over the Lomonosov Ridge, the dominant topographic feature of the Arctic Basin, is relatively small and indicates rocks with low but rather uniform magnetic susceptibility. Abnormally flat profiles over the Nansen Sill between Greenland and Spitsbergen suggest the presence of nearly nonmagnetic rocks, and there is no magnetic indication here of the midoceanic ridge that has been inferred from earthquake-epicenter data.

Preliminary trials of a radiometric technique for continuous-traverse measurement of gamma radioactivity and bulk density of in-situ bottom sediments were conducted from a Coast Guard cutter in Lake Superior by C. M. Bunker and M. D. Shutler. The radioactivity measurements were proved feasible, and the bulk-density measurements can probably be made following instrument modification.

Marine geochemistry

Dorothy Carroll has determined the mineralogy, grain-size distribution, and ion-exchange capacity of numerous sea-floor sediment cores collected by the Navy Hydrographic Office from near the Gulf of St. Lawrence and by the Coast and Geodetic Survey and the Atomic Energy Commission off the east coast of the United States. The northern sediments are mostly silty clays containing chlorite and detrital mica. Cores from off the New Jersey coast are mostly *Globigerina* oozes, but the lower part of a core from 2,000 fathoms is probably red mud. There is more clay 2 to 3 feet below the surface than at the surface, and the deeper clay minerals are better crystallized. Chlorite is probably largely detrital but may also be authigenic. Organic carbon is not abundant in the Atlantic cores. The ion-exchange capacity of the sediments ranges from 3 to 30 milliequivalents per 100 grams.

About 35 glauconite samples ranging in age from Cambrian to Recent have been examined by X-ray diffraction (Fe-Kα radiation). They range from micas that have a crystallinity very similar to that of Fithian illite, to mixtures of mica and chlorite, mica-chlorite-montmorillonite, and chlorite (chamosite?).

A sample of clean pellet-form glauconite put under a pressure of 3,000 psi for 1 month by E. G. Robertson was unchanged in appearance, and X-ray patterns before and after treatment were identical, indicating that some glauconite is stable under load pressure. Experiments are continuing at increased pressures.

The Deuterium content of ocean water is discussed on page A95.

PERMAFROST STUDIES

Data obtained in 1960 from reconnaissance observations of the active zone of permafrost in Kronprins Christian Land and Peary Land, North Greenland,

[53] Deevey, E. S., Jr., 1939, Studies on Connecticut lake sediments: Am. Jour. Sci., v. 237, p. 691–724.

shows that the ice-cemented soil is separated from the permanently frozen ground by a dry, ice-free layer from an inch to over 6 inches in thickness. This layer occurs in soils ranging in texture from clay through pebbly and sandy gravel. The area under consideration is extremely arid, and the moisture content of the active zone is generally 20 percent or less during the height of the melting season.

Only one small remnant of permafrost was noted, at a depth of 30 feet, in the outwash deposits in the immediate vicinity of Big Delta, Alaska, T. L. Péwé and G. W. Holmes report. However, they think the deposits were formerly perennially frozen to a depth of at least 100 feet and have subsequently been thawed by water percolating through the more permeable sediments.

Temperature measurements to depths of 1,000 feet in permafrost at high latitudes yield information on recent secular trends in mean annual ground-surface temperature. The data are easily analyzed by heat-conduction theory in the absence of the complicating effects of heat transfer by moving fluids. In a well near Barrow, Alaska, A. H. Lachenbruch, G. W. Greene, and V. B. Marshall report that a recent increase in surface temperature has affected earth temperature to a depth of about 300 feet. Measurements taken during the past 12 years yield the total warming at each depth since the start of the change, and the rate at which the warming is currently taking place. From these data the thermal diffusivity of the permafrost and the history of the surface change can be estimated. The mean annual ground-surface temperature has evidently increased about 4°C since about 1850, with about half of the increase occurring since 1930. Data from other wells under study in northern Alaska indicate that this secular warming is general along the Arctic coast, although it is subject to local variation.

GEOPHYSICS

The following discussion of some recent results from the Geological Survey's program in the field of geophysics is presented under the general headings of theoretical and experimental geophysics and major crustal studies. Findings from regional geophysical studies are related in the previous sections on regional geology and hydrology where they augment the results of other regional field studies.

THEORETICAL AND EXPERIMENTAL GEOPHYSICS

Paleomagnetism

Results of recent paleomagnetic studies on Hawaiian lavas, the age of Hawaiian volcanoes, and the nature of the earth's magnetic field in this region have been described by R. R. Doell and A. V. Cox (1961b). Wide lateral and stratigraphic sampling has failed to locate rocks possessing reversed polarities; thus, all lavas on Hawaii now above sea level probably were extruded since the magnetic field last had a reversed polarity. The age of the "reversal" zone is not precisely known, but it probably occurred about half a million years ago. These paleomagnetic results have also shown that secular variation in this region is materially less than it has been elsewhere during the last 200 years, and was also probably quite low for long periods in prehistoric times.

Magnetic properties of rocks

Detailed magnetic measurements by A. V. Cox, R. R. Doell, and Y. Arai of basalt cores taken from the bottom of test hole EM–7, Guadalupe Island, show that: (1) the basalt layer is reversely magnetized, (2) the natural remanent magnetization is extremely stable and of thermoremanent origin, (3) induced magnetization is less than 5 percent of the remanent magnetization, decreasing to about ½ percent at the upper surface, and (4) the Curie temperature is several hundred degrees below that for pure magnetite. These data strongly suggest that average magnetic properties cannot be properly determined from measurement of material dredged from the top of submarine lava flows, and that interpretation of magnetic anomalies in oceanic areas must be based on remanent magnetism, not induced magnetism.

A magnetic-susceptibility and vertical magnetic-field strength probe was designed and used by C. J. Zablocki in preliminary hole EM–9 of the Mohole project near Guadalupe Island. No appreciable amounts of moderately paramagnetic or ferromagnetic minerals were detected in the zones of sedimentary rock above the basalt. The bottom section of the hole filled and prevented logging of the basalt layer.

Stress waves in solids

Measurements by L. Peselnick and R. Meister of the S and P waves as a function of density for a monomineralic material (limestone) has shown a linear dependence of the velocity with density.

Because of conflicting data in the literature on the elastic constants of calcite, new measurements were made by Peselnick and R. A. Robie. Their results agree with the earlier work of Voigt [54] and Bhimasenachar [55] and disagree with the recently published data of Reddy and Subrahmanyam.[56]

[54] Voigt, Waldemar, 1910, Lehrbuch der kristallphysik: B. G. Teubner, Berlin.

[55] Bhimasenachar, J., 1945, Elastic constants of calcite and sodium nitrate: Indian Acad. Sci. Proc., v. 22, sec. A, no. 4, p. 199–208.

[56] Reddy, P. J., and Subrahmanyam, S. V., 1960, Thermo-elastic behavior of calcite: Acta Cryst., v. 13, p. 493–494.

Rock deformation

Laboratory observations have been made of fracture and flow of rocks under a large variety of conditions, of creep and rupture of metals tested under various conditions, and of a few incidental observations of rock breakage in mines. E. C. Robertson states that it is possible to make some generalizations about the deformation of all these materials in terms of strain, temperature, stress, and time, and in terms of ductility versus brittleness. For a given strain rate, at least in the region of observation, of 10^{-8} sec^{-1} to 10^{3} sec^{-1}, an increase of temperature compensates for increase of stress difference for the sample to remain ductile; at a given temperature, a decrease of strain rate compensates for an increase of stress difference to maintain ductility; and the effect of decreasing the hydrostatic pressure, for constant strain rate and stress difference, can be compensated by increasing temperature, to maintain ductility.

Thermochemical data

R. A. Robie is evaluating thermochemical data from the literature, paying special attention to the sulfides. The thermodynamic properties of 30 minerals and related substances have been tabulated for 100° intervals. A tabulation of molar volumes and densities and unit-cell parameters has been prepared, in collaboration with Phillip Bethke, for the Geological Society of America's "Handbook of Physical Constants."

Electrical investigations

Model studies for the turam method, using graphite and carbon models immersed in a brine-filled tank, were made by G. I. Evenden and F. C. Frischknecht. Comparison of results using a large insulated loop with those using a long grounded wire show that the contribution to anomalies from ground-return currents may be large when using a long grounded wire as a source.

Electrical-resistivity logs were made by C. J. Zablocki in 13 deep prospect drill holes penetrating metasedimentary and igneous rocks of the Adirondack area of New York. Because these rocks have relatively low permeability from fracturing and consequently have a low water content, they are less conductive than the igneous rocks of the Western United States.

Electrical properties of the earth's crust

In cooperation with the Advanced Research Projects Agency, Department of Defense, G. V. Keller and others have started an intensive study to determine the electrical properties of the earth's crust by means of several concurrent investigations: (1) compilation from electrical well logs of the resistivity of near-surface rocks; (2) measurement of resistivity of rocks from 5 to 50 miles deep by large-scale resistivity soundings and by the magneto-telluric method;[57] (3) observation of telluric currents and their relations with local geology; and (4) observation of the characteristics and attenuation of electromagnetic signals generated by underground nuclear explosions.

Preliminary work has indicated that the electrical properties of a rock may be predicted within fairly close limits when its lithology, geologic age, and tectonic environment are known—data which are generally available from the geologic literature. Because the procedures of sampling rocks usually alter their electrical properties, laboratory determinations are unsuitable for predicting their in-place electrical respone. Better data for establishing the nominal electrical properties of rocks of varying lithology, geologic age, and tectonic environment are afforded by electrical logs of oil wells and prospect drill holes. Selected groups of logs are being obtained and processed for analysis by a digital computer.

Few data are available on the electrical properties of the deeper layers of the crust, so resistivity soundings are being made on an unprecedentedly large scale. For obtaining information about rocks several tens of kilometers deep, a direct-current dipole is set up with 100 electrodes grounded at each end of a heavy cable 3 miles long and attached to storage batteries adequate to force currents of 5 to 20 amperes through the ground. The resulting electric-potential field is measured with a short dipole of potential-measuring electrodes at distances as great as 35 miles from the current dipole. Deep soundings have been made in central New Hampshire, in northwestern Maine, in southern Nevada, and in central Arizona.

In the White Mountains of central New Hampshire, a surface layer about 50 meters thick is composed of weathered granite and has low resistivity; the massive granite at greater depths has very high resistivity. At a depth of somwhat less than 10 kilometers the resistivity is again low, probably because of a lithologic change. In northwestern Maine, the metamorphosed sedimentary rocks at one location and the igneous rocks (including granite and felsite) at another location gave electrical results similar to those in the White Mountains, despite the lithologic differences. In southern Nevada, near-surface Paleozoic carbonate rocks about 12 kilometers thick have moderately high resistivity and overlie basement rock, possibly volcanic, of considerably lower resistivity. In central Arizona, alluvium and volcanic rocks of very low resistivity comprise a surface layer as thick as several kilometers and overlie a high-resistivity basement thicker than 40 kilometers.

[57] Cagniard, Louis, 1953, Basic theory of the magneto-telluric method of geophysical prospecting: Geophysics, v. 18, no. 3, p. 605–635.

A preliminary survey of the telluric field in an area of the Front Range west of Denver, Colo., revealed strong polarization of the electric field perpendicular to the contact between the resistive rocks of the Front Range and the conductive sediments of the Denver–Julesburg Basin.

Transient electromagnetic signals generated by underground nuclear explosions were observed at various distances from ground zero of some of the winter 1961–62 series of tests at the Nevada Test Site. With broad-band recording, the electromagnetic signal decreased to the ambient noise level about 10 miles from ground zero.

Induced polarization

Induced polarization contributed by overvoltage effects in pyritic sandstones has been found to depend upon current density, the size and distribution of the metallic grains, and resistivity of the matrix as well as total sulfide content. Laboratory studies have shown that all these variables affect polarization as expected. Overvoltage measurements by L. A. Anderson and G. V. Keller on a single-crystal of pyrite showed that the specific surface resistance of the crystal decreases rapidly as the current density is increased. Measurements on natural samples in the laboratory indicate that fairly large amounts of pyrite are necessary to provide polarization in excess of background level caused by electrolytic polarization. A field survey, however, demonstrated the effectiveness of the induced-polarization method in detecting volume percentages of pyrite as low as 2 percent. The most reliable approach to polarization analysis is believed to be through overvoltage measurements that provide the basic data necessary for distinguishing between electrometallic and electrolytic polarization.

Luminescence

Barnes [58] has shown that a wide variety of minerals fluoresce in the infrared part of the spectrum, upon excitation by visible light. His instrumentation, however, did not permit examination of phosphorescence. R. H. Barnett and R. M. Moxham [59] devised laboratory instruments to observe and record infrared phosphorescence, using a pulsed-excitation technique. Kyanite, fluorite, and scheelite, among a dozen minerals examined, have phosphorescence decay times on the order of a few milliseconds that are detectable with an infrared-sensitive photomultiplier. The laboratory instruments are being adapted for field exploration.

Interpretation methods

In magnetic interpretation it is desirable to distinguish anomalies due to basement relief (suprabasement anomalies) from those due essentially to susceptibility contrasts within the basement complex (intrabasement anomalies). R. G. Henderson, using the electronic computer, simulated theoretical fields typical of the two cases, and applied the downward-continuation option of his "comprehensive system" [60] to compute the fields at the level of the basement surface. Preliminary results, obtained thus far only for the suprabasement anomaly, show a characteristic pattern.

To obtain geologically significant residual anomalies from complex geophysical maps, it has been found necessary to fit the regional effects with least-squares polynomial surfaces of relatively high degree. The computer program has been accordingly extended by W. L. Anderson to include surfaces up to the 15th degree. Studies by Henderson are directed toward establishing criteria for the degree appropriate to a given map.

Power spectral-density analyses have been investigated by Henderson with a view to preparing computer programs for treating digitized seismic and other time-function data. An elaborate system for interpreting seismic reflection and refraction reversed profiles in crustal-studies investigations has been outlined and flow-charted by B. F. Grossling and is being programmed by W. L. Anderson.

Quantitative interpretation of aeromagnetic anomalies has been based for the most part on the use of physical models in which the direction of magnetization is parallel to that of the earth's field, although laboratory results show that this assumption is invalid for many rock units. I. Zietz reports that magnetic fields have been calculated for inclinations of magnetization significantly different from that of the earth's present field. The calculations are for a rectangular flat-topped mass with infinite vertical sides and a 75° inclination of the earth's field. Several significant empirical relations between the physical model and the computed fields have been obtained. For low dips of magnetization the maximum and minimum points, rather than the points of inflection, mark the edges of the rock masses. The depth-calculation techniques described by Vacquier and others [61] are based on the assumption of induced polarization, but these same empirical rules can be applied equally well to the total-intensity field when remanent magnetization is present. This probably explains the success of the methods when applied to observed aeromagnetic anomalies over sedi-

[58] Barnes, D. F., 1958, Infrared luminescence of minerals: U.S. Geol. Survey Bull. 1052–C.

[59] Barnett, R. H., and Moxham, R. M., 1961, Infrared phosphorescence detection using pulsed excitation: Rev. Sci. Instruments, v. 32, no. 2, p. 740–741.

[60] Henderson, R. G. 1960, A comprehensive system of automatic computation in magnetic and gravity interpretation: Geophysics, v. 25, no. 3, p. 569–585.

[61] Vacquier, V., and others, 1951, Interpretation of aeromagnetic maps: Geol. Soc. America Mem. 47, 151 p.

mentary basins. For rock units having large remanent magnetization, the dip of the magnetization may be estimated from the ratio between the maximum- and minimum-anomaly amplitudes, and the declination may be approximated from the horizontal line between the locations of the extreme values. The method has been successfully applied to aeromagnetic data taken over volcanic buttes near the Bearpaw Mountains, Mont.

Geophysical Abstracts

The Geological Survey continued quarterly publication of Geophysical Abstracts for its 34th year. Abstracts were derived from more than 500 journals in 20 languages, and increased by approximately 200 abstracts over the number published in 1961. The staff and volunteer abstracters cover literature pertaining to physics of the solid earth, application of physical methods and techniques to geologic problems, and geophysical exploration.

MAJOR CRUSTAL STUDIES

Long-range seismic refraction

With the support of the VELA UNIFORM Program of the Advanced Research Projects Agency, Department of Defense, the Geological Survey has undertaken a seismic-refraction exploration of the continental crust of western conterminous United States. An immediate goal of this exploration is the determination of improved traveltime curves needed in the evaluation of some fundamental problems in nuclear-test detection. Long-range objectives include the measurement of the gross physical properties of the crust and upper mantle and the correlation of these parameters with physiographic provinces and major geologic structures. The methods used are those that were used by the Carnegie Institution of Washington in its pioneering work on the exploration of the crust and, later, by the University of Wisconsin and others.

The 1961 field effort was concentrated in the California-Nevada region, where a contractor, United ElectroDynamics, Inc., provided major support for the field program and the preliminary interpretation of the records. Seventy-six chemical explosions ranging in size from 250 pounds to 10,000 pounds were detonated in bodies of water or in drill holes at 10 shotpoints to provide signals for more than 3,500 km of refraction coverage along 6 major profiles.

A preseason training and procedure-development exercise in eastern Colorado provided 600 km of profile along 2 lines from a series of chemical explosions in Nee Granda Reservoir. The post season GNOME nuclear explosion was recorded by 10 Survey units and 1 Colorado School of Mines unit at ranges of 31 km to 431 km along a line extending northward from Carlsbad in eastern New Mexico.

Eastern Colorado and New Mexico

Assuming a crust composed of uniform flat-lying layers, each having a *P*-wave speed greater than that in any layer above it, W. H. Jackson, S. W. Stewart, and L. C. Pakiser deduced an approximate structure of the crust in eastern Colorado from the traveltime curve of the unreversed profile extending northward from Nee Granda Reservoir to Sterling, Colo. *P*-wave speeds and thicknesses of the major layers are: near-surface material, 3.9–5.2 km per sec, 2.3 km; upper crustal layer, 5.8 km per sec, 9.7 km; lower crustal layer, 6.1 km per sec, 19.1 km; intermediate layer, 6.7 km per sec, 17.2 km; upper mantle, about 8.0 km per sec. The depth to the top of the mantle is 48.3 km.

Pakiser and Stewart computed a very similar structure for the crust in eastern New Mexico from the GNOME traveltime data. Augmenting the GNOME data with that from pre-GNOME experiments which established a near-surface speed of about 4.6 km per sec, the speed and thickness of the crustal layers were found to be: near-surface material, 4.6 km per sec, 4.0 km; major crustal layer, 6.2 km per sec, 19.4 km; intermediate layer, 7.0 km per sec, 25.2 km; upper mantle, 8.2 km per sec. The depth to the top of the mantle is 48.6 km, in rather close correspondence to that in eastern Colorado.

Along both of these profiles, particularly that from GNOME, waves refracted along the top of an intermediate layer were first arrivals over a range of several tens of kilometers.

California and Nevada

Refraction lines in California and Nevada, reported by J. H. Healy and others, traversed a number of physiographic provinces: Basin and Range, Sierra Nevada, Central Valley of California, and Coast Ranges. Except for lines shot from San Francisco, where the low apparent speed of 5.4 km per sec for the major crustal layer was indicated by data from a profile between San Francisco and Fallon, Nev., the apparent speed of P_g lay between 5.9 km per sec and 6.3 km per sec, with an average near 6.1 km per sec. Apparent speeds of P_n were low (7.6 to 7.8 km per sec) in the Basin and Range province and higher (8.0 to 8.4 km per sec, average about 8.1 km per sec) along the Pacific coast. With the possible exception of lines shot from San Francisco, an intermediate layer with a speed near 7.0 km per sec was not represented by first arrivals on the California-Nevada profiles. Prominent secondary arrivals along some profiles, such as Eureka, Nev., to Fallon, Fallon to Eureka, and Fallon to San Francisco, suggest an intermediate layer with a speed near 6.9 km per sec.

A simple flat-layer interpretation of the Eureka to Fallon traveltime data yields the following crustal structure: near-surface layer, 4.8 km per sec, 2.7 km; major crustal layer, 5.9 km per sec, 14.8 km; intermediate layer, 6.9 km per sec, 17.4 km; upper mantle, 7.7 km per sec. The depth to the top of the mantle is 34.9 km. A crust of nearly the same total thickness was computed from the Fallon to San Francisco profile for the Sierra Nevada (along Highway 50). Beneath the region of Carson Sink, however, the depth to the top of the mantle appears to be somewhat less than 30 km on the basis of the Fallon to Eureka profile.

Very high apparent speeds in first arrivals between 120 and 160 km and relatively early first arrivals beyond 160 km on the San Francisco to Fallon profile suggest a large structural anomaly beneath the central part of the Central Valley of California. Possible explanations of these traveltime anomalies include that of an "antiroot" beneath the Central Valley, with the mantle bulging upward beneath the deep valley sediments.

Gravity studies of the Snake River Plain

Significant gravity anomalies over the eastern Snake River Plain described by T. R. LaFehr and L. C. Pakister are: (1) a broad high which is an extension of the large gravity highs of the western plain; (2) a set of alternating, elongated lows and highs normal to the trend of the eastern plain; and (3) a prominent low over Mud Lake.

The low-amplitude anomalies of the eastern plain contrast sharply with the high-amplitude en-echelon gravity highs of the western plain reported by D. P. Hill, H. L. Baldwin, and L. C. Pakister (1961), and suggest a structural dissimilarity between the eastern and western parts of the plain.

Secular deformation of the Great Basin

A value of approximately 10^{21} poises for the viscosity of the mantle beneath the eastern Great Basin has been derived by M. D. Crittenden, Jr., from a study of the rate of isostatic recovery of Lake Bonneville. Curves representing the deflection at the center of the changing load of Lake Bonneville water, where this changing load of water was deduced from curves by Roger Morrison (1961d) showing the variation in lake level during the last 60,000 years, were constructed for various assumed viscosities. Comparison of these curves with the amount and timing of observed uplift permitted the selection of the appropriate viscosity, which is limited in accuracy to about one order of magnitude by uncertainties in the dating of Lake Bonneville events.

Sierra Nevada

An analysis of releveling data in the central Sierra Nevada obtained from the U.S. Coast and Geodetic Survey indicates that there has been a significant amount of internal deformation within the mountain range between surveys in 1940 and 1957. Changes in the elevation of bench marks west of Tenaya Lake are quite small and within the limits of probable error, but the eastern Sierra has been tilted upward to the east at the average rate of 0.1 μrad per year. This tilt rate is comparable to the current rate of isostatic rebound from the glacial loading in Fennoscandia, but is probably of tectonic origin. These data support the conclusion by H. W. Oliver [62] based on gravity observations that the eastern half of the Sierra is slightly overcompensated.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

Many members of the Geological Survey are presently occupied in both field and laboratory studies in geochemistry, mineralogy, and petrology. This work is concerned primarily with such topics as the description of new minerals, crystal structure of minerals, physical and chemical properties of rocks and minerals, distribution and abundance of the elements in minerals, rocks, and water, physical and chemical conditions during ore deposition, and studies of organic processes and materials. Results from many of these general areas of investigation are reported in the following section. Research in these subjects may also be reported elsewhere in this chapter, such as, isotope and nuclear studies page A93; resource investigation, page A1; geochemical and botanical exploration, page A121; radioactive-waste disposal, page A112; marine geochemistry, page A80; spectroscopy, page A118; and distribution of elements as related to health, page A115.

EXPERIMENTAL GEOCHEMISTRY AND MINERALOGY

Mineralogical studies and description of new minerals

G. T. Faust and J. J. Fahey (1962) have restudied the serpentine-group minerals by a variety of physical and chemical techniques and have determined the structural formula of this group to be $X_nY_mO_{10}(OH)_8$, where X is a divalent ion and n ranges in value from 6.04 to 5.81, and Y is mostly Si and m ranges in value from 4.00 to 4.09.

Margaret Foster has calculated the structural formulas of vermiculites and hydrobiotites from modern chemical analyses. She finds that these minerals resemble phlogopites and magnesian biotites in structural composition, although with certain interpretable differences. On the basis of composition and charge relations, vermiculites may be considered as formed from phlogopites or magnesian biotites by replacement of K by Mg.

The compound $Cu_{1.96}S$, previously known only as a synthetic compound, has been identified in nature by E.

[62] Oliver, H. W., 1960, Gravity anomalies at Mt. Whitney, California: Art. 146 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B313–M315.

H. Roseboom. The mineral, named djurleite, has been found to occur in a number of places, including localities in Mexico, Peru, southwest Africa, and Butte, Mont. Although the mineral should prove to be a widespread occurrence, its similarity in appearance to chalcocite will slow down its recognition. The two minerals, however, can be differentiated by X-ray diffraction methods. Djurleite may well be a significant temperature indicator, because it is unstable above 100°C.

Charles Milton has studied a nearly monomineralic carbonate rock extruded from the active Oldoinyo Lengai volcano, Tanganyika, Africa. The new, unnamed mineral comprising the bulk of the rock has the composition

$$(Ca_{.94}Sr_{.05}Ba_{.01})CO_3.(Na_{2.03}K_{.40})[(CO_3)_{1.12}(SO_4)_{.06}(Cl)_{.01}(F)_{.01}(OH)_{.04})].$$

In cooperation with the Geological Survey of Israel, Milton has investigated the remarkable mineralization of the "limestone" rocks of the Hatrurim region near the southern end of the Dead Sea. These rocks consist largely of such minerals as spurrite, $2\ Ca_2SiO_4 \cdot CaCO_3$, hydrogarnets, $3CaO \cdot Al_2O_3 \cdot 6H_2O$ and $3CaO \cdot Fe_2O_3 \cdot 6H_2O$, and barite, $BaSO_4$, enclosing such garnets. Present in some rocks are portlandite, $Ca(OH)_2$, afwillite $Ca_3(SiO_3OH)_2 \cdot 2H_2O$, ettringite, $Ca_6Al_2[(OH)_4(SO_4]_3 \cdot 26H_2O$, vaterite, $CaCO_3$, tobermorite $Ca_5H_2(Si_3O_9)_2 \cdot 2H_2O$, plombierite, $Ca_5H_2(Si_3O_9)_2 \cdot 6H_2O$, and several new species as yet unnamed.

In a study of the alkalic dike rocks of Augusta County, Va., Milton and collaborators have isolated and identified well-crystallized bastnaesite, and probably also labuntsovite-nenadkevichite (complex Ti-Nb silicates). Milton has shown that northupite, $Na_3Mg(CO_3)_2Cl$, may contain ferrous iron substituting for magnesium, amounts up to that given by the ratio Fe:Mg=3:7.

X-ray diffraction studies by D. E. Appleman have proved the validity of melanophlogite as a mineral. It is essentially a cubic polymorph of SiO_2 (a=13.41 A), apparently having a zeolite-like structure that can accommodate an appreciable amount of elementary sulfur, which can be driven off with heat without destroying the silica framework.

A new mineral, wegscheiderite, having the formula $Na_2CO_3 \cdot 3NaHCO_3$, has been described by J. J. Fahey, K. P. Yorks, and D. E. Appleman (1962) from occurrences in the Green River Formation, Sweetwater County, Wyo.

Single-crystal X-ray studies by Marie Lindberg have permitted the complete characterization of two new vanadium minerals and a new uranium molybdate mineral, initially investigated by Alice Weeks and coworkers. The first of these is found in Montrose County, Colo., and is a calcium vanadyl vanadate of formula $Ca_2H_xV^{+4}_{(1+x)}V^{+5}_{(8-x)}O_{24} \cdot 8H_2O$, where $x \leqq 0.1$. The second, found in vanadium-uranium deposits in Montrose County, Colo., is a potassium vanadyl vanadate; the purplish-blue uranium molybdate occurs in western Karnes County, Tex.

Potentiometric studies by A. M. Pommer and Dorthy Carroll of a hydrogen-montmorillonite, using hydrogen- and cation-sensitive glass electrodes, indicate that the clay functions as a mixture of two acids because of the presence of two types of exchange sites, interlayer and edge, both occupied by hydrogen ions. The interlayer sites, which hold the hydrogen ions less tightly, cause the stronger acid function, and the edge sites, which form stronger hydrogen bonds, cause the weaker acid function. In the case of beidellites, the pattern is reversed. Application to the clay of Eisenman's theory of an atomic selectivity suggests that the stronger acid sites are more likely to hold cesium preferentially. This would be of interest in considering the problem of disposal of radioactive cesium-137 in wastes.

J. J. Fahey (1962) has published the results of an extensive study of the mode of occurrence of the saline minerals in the Green River formation, the paragenetic relation of the minerals, and the economic importance of the trona deposits. Also included is a section by Mary Mrose on X-ray powder data for saline minerals.

Crystal chemistry

Further studies aimed at a better understanding of structural states and the nature of aluminum-silicon ordering in feldspars have been made. A more detailed examination has been made of reedmergnerite, the boron analog of feldspar, by D. E. Appleman and Joan Clark, and of the iron synthetic analogs of the feldspars by D. R. Wones and D. E. Appleman (1962). It appears most probable that the degree of order in low-temperature feldspars, if not complete, is much greater than has heretofore been considered.

C. L. Christ and Joan Clark have continued their systematic study of the structure and crystal chemistry of the hydrated borate minerals. In collaboration with D. E. Appleman, the crystal structures of the five calcium borates in the series $2CaO \cdot 3B_2O_3 \cdot nH_2O$, with n= 1 (synthetic, sheet structure), 5 (colemanite, chain), 7 (meyerhofferite, polyion), 9 (synthetic, polyion), and 13 (inyoite, polyion), all of which have been previously solved in this program, were subjected to intensive refinement to determine positions with high accuracy. This work was carried out with a comprehensive new least-squares analysis program written for the Geological Survey's B220 computer by D. E. Appleman and J. Marsheck, using some 15,000 independent X-ray data.

As a result, the most accurate distances and angles ever measured for borate structures have been obtained, and these data should eventually provide the basis for a chemical-bond theory for borates as well as an explanation for the hydrogen bonding found in these crystals.

A new structure analysis of sarcopside by Mary Mrose and D. E. Appleman shows that its essential composition is $(Fe,Mn,Ca)_3(PO_4)_2$. A close structural relation was found between this monoclinic mineral and the orthorhombic minerals lithiophyllite, $LiMnPO_4$, heterosite, $(Fe,Mn)PO_4$, and lithiophosphate, Li_3PO_4.

Malcolm Ross and H. T. Evans, Jr., (1962) have continued their investigation of the detailed crystal structure of the members of the metatorbernite group, including $K(UO_2AsO_4)\cdot 3H_2O$ (abernathyite), $NH_4(UO_2AsO_4).3H_2O$, $K(H_3O)(UO_2AsO_4)_2.6H_2O$, and $Cu(UO_2PO_4)_2\cdot 8H_2O$ (metatorbernite).

Malcolm Ross has completed a critical and comprehensive review of the crystal chemistry of all known beryllium minerals, in a study directed toward the establishment of ideas that may be useful in the search for beryllium. He found that beryllium, like silicon, always occurs in tetrahedral coordination with oxygen, with the Be–O bond length about 1.64 A. Beryllium will proxy for silicon, but only under certain favorable conditions of charge balance in the crystal structure.

Experimental geochemistry

Research was continued on the system $NaAlSi_3O_8$–$LiAlSiO_4$–SiO_2–H_2O by D. B. Stewart. The rarity of petalite ($LiAlSi_4O_{10}$) reflects its very limited field of stability; many of the intergrowths of spodumene ($LiAlSi_2O_6$) and quartz reported from lithium pegmatites have the same composition as petalite and have recrystallized from petalite during slow cooling of pegmatite. In zoned pegmatites, feldspar-petalite assemblages may be the high temperature–low pressure chemical equivalent of the more abundant feldspar-spodumene-quartz assemblages.

Stewart has discovered that at least 25 weight percent $LiAlSiO_4$ can occur stably in solid solution in quartz. At 2 kilobars the solid solution can coexist with siliceous β-spodumene solid solutions or petalite, and is stable from at least 650°C to 830°C. Quartz from lithium-rich pegmatites does not contain significant amounts of lithium or aluminum, thus it is probable that the quartz crystallized at low temperatures, or recrystallized at low temperatures from any solid solution initially present.

The point where albite, quartz, silicate melt, and gas coexist in the system $NaAlSi_3O_8$–SiO_2–H_2O has been redetermined by Stewart to be 735±5°C at 2 kilobars H_2O pressure, and the ratio of solid components in the melt is $NaAlSi_3O_8:SiO_2=62:38$.

H. R. Shaw (1962) has calculated the solubility of H_2O in silicate melts by the methods of statistical thermodynamics. Binary, or approximately binary, portions of the system $CaAl_2Si_2O_8$–$KAlSi_3O_8$–$NaAlSi_3O_8$–SiO_2–H_2O were considered, and with the limited experimental data available agreement was obtained with theory.

J. J. Hemley (1962) has continued his investigations of the systems Na_2O–Al_2O_3–SiO_2–H_2O and K_2O–Al_2O_3–SiO_2–H_2O at elevated temperatures and pressures, with consideration being given to extrapolation of results of lower temperatures to provide information important to chemical weathering of rocks.

Results of investigations of the system K_2O–Al_2O_3–SiO_2–H_2O–SO_3 by Hemley and A. J. Gude have yielded stability relations for the phases muscovite, alunite, and kaolinite at temperatures of 100°C to 400°C. These data are consistent with the occurrence of the assemblage alunite–kaolinite found in many acid-sulfate hot springs.

P. B. Hostetler (1962) has completed a study on the thermodynamic stability and surface energy of brucite in water at 25°C. Hostetler and R. M. Garrels (1962) have completed a study on the mechanism of the transportation of uranium and vanadium in low-temperature aqueous solutions and the deposition of minerals of these elements from such solutions in sandstone-type deposits.

R. O. Fournier and J. J. Rowe [63] have determined the solubility of cristobalite in liquid water to temperatures up to 250°C. At 25°C the solubility is 27 ppm and at 250°C it is 730 ppm.

Extensive studies on various geochemical aspects of the origin and mechanism of ore deposition have continued. P. Toulmin, 3d, and P. B. Barton, Jr., (1962) have obtained data through the use of the electrum tarnish method that permits derivation of an equation relating the fugacity of sulfur, the temperature, and the mole fraction of FeS dissolved in pyrrhotite. Barton and others (1962) have examined the conceptual problems attendant upon applying experimental data obtained on sulfide minerals under equilibrium conditions to actual mineral assemblages; Bethke and others (1962) have considered the results of detailed examination of ore-mineral suites from fissure veins to correlate the laboratory results.

J. S. Wahlberg and J. H. Baker are studying the adsorption of strontium on clay materials. They have found that for the adsorption of strontium from a calcium solution, the exchange can be described by the mass-action equation. However, for the adsorption of

[63] Fournier, R. O., and Rowe, J. J., 1962, The solubility of cristobalite along the three-phase curve, gas plus liquid plus cristobalite: Am. Mineralogist (In press).

strontium from a sodium-plus-calcium solution, the exchange is more exactly described by the electric double-layer theory.

In studies by Wayne Hall and Irving Friedman, analyses of sodium, potassium, calcium, magnesium, chloride, sulfate, boron, and relative deuterium content have been made of fluid inclusions from ore and gangue minerals from the Illinois-Kentucky fluorite district and the Upper Mississippi Valley district. Changes in composition seem to reflect changes in the nature and composition of the ore-depositing solution.

E. H. Roseboom has completed measurement of the cell edges of the natural and synthetic diarsenides of Co and Fe (safflorite-loellingite). The mutual solubilities of PbS and PbTe, and the solubility of CdS in galena, were investigated by Philip Bethke. Brian Skinner and Roseboom have synthesized hauerite (MnS_2) by hydrothermal methods. This is a key compound in the systems Zn–Mn–S and Fe–Mn–S.

The problem of the thermodynamic characterization of a random mixed-layer clay mineral has been considered by E-an Zen.[64] Zen (1962) has continued his studies of the system $CaSO_4$–NaCl–H_2O at low temperatures and 1 atmosphere.

A. H. Truesdell (1962b) has investigated the chemical alteration of natural glasses through their behavior as membrane electrodes.

Chemistry of natural water

A provisional equilibrium constant of $10^{-82.0}$ was obtained by W. L. Polzer for the reaction

$$\underbrace{H_4Al_2Si_2O_{9(solid)}}_{\text{kaolinite}} + 5H_2O_{(liq)} = 2Al^{+3}_{(aq)} + \underbrace{2H_4SiO_{4(aq)}}_{\text{silicic acid}} + 60H_{(aq)},$$

for the system kaolinite-water in the laboratory at room temperature and under 1 atmosphere pressure of carbon dioxide.

The solubility of kaolinite is apparently increased by using finely ground (passing 100 mesh) material. Disturbance of the surfaces of the kaolinite produced by grinding is probably responsible for this effect.

Concentrations of manganese common in natural water generally can be attributed to Mn^{+2} ionic species complexed to some extent with HCO_3^{-1} and SO_4^{-2}. Small amounts of these forms are stable in aerated water below about pH 8.0. At high pH or with strong oxidation, Mn^{+3} and Mn^{+4} oxides are formed. The rate of oxidation is increased by raising the pH and decreased by raising HCO_3^{-1} and SO_4^{-2} activities. These relationships have been summarized in graphical form by J. D. Hem (1962a).

[64] Zen, E-an, 1962, Problem of the thermodynamic status of the mixed-layer minerals: Geochim. et Cosmochim. Acta (In press).

FIELD GEOCHEMISTRY AND PETROLOGY

Studies of igneous rocks

R. E. Wilcox (1961) has concluded from a study of volcanic rocks of the Aleutian Islands that albite in spilitic and keratophyric rock suites is attributed mainly to albitization after emplacement rather than to primary crystallization from soda-rich magma. This conclusion is based on the fact that the coexisting pyroxenes are not sodic types as might be expected from crystallization of soda-rich magma, but instead are common augite, typical of normal labradorite-bearing basalt.

T. P. Thayer and C. E. Brown have found evidence of at least two generations of flow layering in gabbro and peridotite in the John Day district, Oregon. The layering is characterized by parallel foliation and lineation and by contrasts in mineral composition that are not found in stratiform complexes, and it cuts across major rock boundaries without deviation. Layering in relict folds cut by the dominant foliation and lineation shows similar mineralogic variations. All of the layering now found is believed, therefore, to have been formed by flowage which destroyed all traces of any primary layering due to crystal settling.

Studies of metamorphic rocks

Comparative studies of unmetamorphosed rock sequences and their metamorphic equivalents by A. E. J. Engel and Celeste Engel show that both metamorphic differentiation and mafic metasomatism are ubiquitous and quantitatively important processes in rocks reconstituted above the epidote-amphibolite facies. In general, these metamorphic terranes contain many more lenses and layers of granitic and amphibolitic (basaltic) composition than their unmetamorphosed analogs. That much of the granite is of metasomatic, metamorphic, and anatectic origin, that is, the result of incipient melting and granitization of pre-existing rock types in these terranes, is demonstrable and widely recognized. In contrast, amphibolitization of equally diverse rock types is not generally recognized although it is complementary to, and as common a process as, granitization. Field and laboratory studies by the Engels of rocks from many parts of the world show that most thinner amphibolite interlayers and mafic granulites have formed from less mafic sedimentary and igneous parent rocks by metamorphic differentiation and mafic metasomatism.

Field, petrographic, mineralogical, and chemical studies by R. G. Coleman, R. C. Erd, and D. E. Lee show that three different types of Franciscan glaucophane-bearing schists occur in the Cazadero area, California. These three types, although not defined as subfacies within the glaucophane schist facies, do reflect a range of progressive metamorphic conditions, and they appear to have developed by isochemical metamorphism from the same original rock types (mostly basalt and graywacke). They also have discovered that much of the confusion that has attended the Franciscan glaucophane schist problem to date results from the fact that the higher grade schists do not occur in place as mappable units, but owe their anomalous position overlying lower grade types to active landsliding in the area under study.

Recent studies of the occurrence of scapolite in the Wallace Formation of the Precambrian Belt Series, southern Shoshone County, Idaho, by Anna Hietanen-Makela, have revealed that the scapolite in these rocks originated by recrystallization of evaporites interbedded with the original sediments and not by introduction of chlorine from magmatic sources as is common elsewhere. The scapolite is distributed in thin biotite-rich layers, parallel to bedding and continuous for several miles, in a host sequence of quartzites, biotite granofelses, and phlogopite-rich quartzose carbonate beds. The stratigraphic sequence is analogous to deposits of quartz sand, mud, and evaporites in present-day salinas.

Studies of sedimentary rocks

Mineralogical analyses by L. G. Schultz, carried on as part of a comprehensive geochemical study of the Pierre Shale with H. A. Tourtelot and J. R. Gill, indicate that nearshore and nonmarine equivalents of the Pierre Shale in central Wyoming and Montana are mineralogically similar to the offshore marine facies of the Great Plains region. The nonmarine and nearshore facies contain larger amounts of the coarser grain constituents—quartz, illite, kaolinite, chlorite, and feldspar—and the nearshore marine facies contain in addition more dolomite. Volcanic-rich sediments in the Livingston Formation and other similar Pierre equivalents contain abundant montmorillonite, mixed-layer clay, and almost as much feldspar as quartz.

E. W. Roedder, using the microscope cooling stage, has found in samples from the Salina (salt) Formation, Goderich, Ontario, minute fluid inclusions that appear to be truly primary and represent samples of seawater of Salina age. They can be distinguished from much-larger secondary inclusions of considerably different composition that occur in nearly all samples. Studies of such inclusions may eventually help delineate the environment under which these extensive salt deposits in the United States and Canada crystallized and later recrystallized.

As part of his study of the Moab 1-degree by 2-degree quadrangle, Colorado and Utah, P. L. Williams has been studying alteration of the Entrada Sandstone. He finds that red, pink, and orange are the "original" colors, whereas white, yellow, and brown colors result from epigenetic processes. Samples of unaltered rock are much richer in heavy minerals than samples of altered rock. In suites of heavy minerals from unaltered rock, detrital grains of magnetite-hematite and ilmenite make up more than half the "heavies," whereas in suites from altered rocks these minerals are sparse or absent, and limonite (pseudopyrite?) is abundant. Among the spectrographically determined components, iron is less abundant in altered sandstone. Although the most permeable rock—the Moab Member—tends to be more altered than the least permeable rock—the Dewey Bridge Member, mapping shows zones of dominantly altered rocks that cut across the three members of the Entrada. Trends and spatial distribution of these zones show no simple relation to the major Laramide (Tertiary) folds, but zones of altered Entrada are common adjacent to faults.

Environments of ore deposition

P. B. Barton, Jr., and Martha Toulmin have experimentally determined the vertical component of the rate of movement of ore solutions that deposited sphalerite and hematite in veins at Creede, Colo. By measuring the settling rates of hematite flakes that occurred as accumulations on the presumed tops of growth zones in sphalerite, they calculated a vertical component of the order of 0.5 centimeters per second, which is in fairly good agreement with indirect estimates made by E. W. Roedder [66] for ore deposits in general.

E. W. Roedder, by means of a detailed study of fluid inclusions in a variety of hydrothermal minerals, is adding important data on the composition of ore solutions. His work confirms the fact that many such minerals are formed from saline solutions rich in NaCl, but he finds that some solutions are rich also in other salts such as $CaCl_2$. Salt concentrations in inclusions in base-metal deposits range from 0 to 15 percent. Salt concentrations in inclusions from Mississippi Valley-type deposits show generally higher but more variable concentrations. He finds that most inclusions in commercial quartz crystal deposits (Brazil, Arkansas, North Carolina) contain 0.1 to 1 molar NaCl equivalent solutions and considerable CO_2.

Geochemistry of hot springs and hydrothermal areas

Studies by G. W. Morey, F. O. Fournier, and J. J. Rowe in Yellowstone National Park indicate that the

[66] Roedder, E. W., 1960, Fluid inclusions as samples of ore-forming fluids: Internat. Geol. Cong., 21st, Copenhagen 1960, Proc., sec. 16, p. 218–229.

chemical composition of the waters in many of the springs and geysers has remained remarkably constant, whereas in others it has changed drastically since the time the waters were first analyzed in 1888. Preliminary analysis of the data indicates that major changes have not come about gradually but rather have occurred in short times as a result of catastrophic events such as the Hebgen Lake earthquake of 1959.

Examination of drilling records showing the occurrence of epidote in hydrothermal areas in various parts of the world has led D. E. White to suggest that epidote may be an important indicator of depth of formation of some hydrothermal alterations. The meager data at hand suggest that epidote may form only at depths greater than 1,500 feet, and that the minimum depth increases with decreasing temperature. Because epidote is a characteristic mineral of "propylitic" alteration of mafic and intermediate volcanic rocks in many epithermal gold and silver deposits, it may be an important clue to the minimum depth of formation of some ore deposits.

Two apparently new ammonium aluminum silicate minerals, one a zeolite and the other a clay, have been discovered by D. E. White and R. C. Erd, at Sulfur Bank, Calif., one of the world's largest ore deposits associated with active hot springs. Their discovery is the result of an active search, stimulated by the fact that ammonium ion constitutes about 30 percent of the total cations in the present thermal waters.

Geochemical distribution of the elements in water

Some tributaries draining the Black Hills in South Dakota contribute heavy metals and other minor constituents to the Belle Fourche River, according to L. R. Petri. Iron, manganese, copper, lead, zinc, arsenic, selenium, cyanides, boron, or sulfides seldom exceed 0.5 ppm, or about 1.5 pounds per acre-foot of water. The concentration of many of the constituents seems to be independent of water discharge, dissolved-solids content of the water, relative percentages of the major constituents in the water, and seasons. A slight dependency on discharge and on dissolved solids is indicated for manganese, arsenic, cyanide, boron, and fluoride, and on seasons for cyanides and managanese. The suspended sediments contain appreciable amounts of some of the minor constituents, and significant amounts of these constituents can be brought into solution by leaching. The amount of minor constituents likely to be added in solution during an average irrigation season is less than 2 pounds per acre; however, the amount likely to be added through the sediments is much greater.

In a joint study of the world's large rivers with the International Union of Geodesy and Geophysics, W. H. Durum and Joseph Haffty observe that median values of ratios Ba/Sr, Ni/Cr, and Ni/Cu are reasonably consistent (within a factor of two) in principal drainage from North America. Median values range from about 1.3 to 2.6. The ratio is slightly greater, however, in global northern latitudes than in southern latitudes. A regression line of best fit to plots of the ratio, R, of Ni to Cu, versus latitude L, takes the form R, $= 0.055L - 0.56$, and the standard error, S_y equals 1.2 (units of ratio). Median values for aluminum, barium, copper, lead, molybdenum, and silver in runoff of North America are the same order as published world averages for ocean water.

Hydrochemical facies in ground water

Research on the hydrology of radioactive-waste disposal at the National Reactor Testing Station in Idaho has included detailed study of the chemical quality of water in basalt aquifers in an area of 894 square miles. Analyses of samples of water from 88 scattered wells, collected from depths a few feet to 200 feet below the regional water table, have enabled F. H. Olmstead to describe 4 distinct hydrochemical facies.

Gerald K. Moore (Art. 115) has shown that the dominant cation facies in the "500-foot" sand of western Tennessee is the calcium magnesium facies and that the bicarbonate type is the major anion facies.

In the Baton Rouge area of Louisiana, C. C. Morgan and M. O. Winner, Jr. (Art. 50) have found that analyses from the recharge area show the cation facies in the ground water to be sodium calcium and the anion facies to be chloride plus sulfate bicarbonate. Due in part to the movement of water through ion-exchange material, the sodium facies occurs near the interface between salt water and fresh water. The bicarbonate facies occurs near the salt-water interface, as it does in the Atlantic Coastal Plain.

P. R. Seaber (Art. 51) has demonstrated that the cation hydrochemical facies present in the ground water in the Englishtown Formation of Late Cretaceous age in the coastal plain of New Jersey are dependent upon ground-water movement, geology, and topography. A calcium magnesium hydrochemical facies occurs in the subsurface recharge area of the formation underlying a topographic high. A sodium potassium hydrochemical facies occurs at depth in the formation, presumably as a result of ion exchange with montmorillonite.

In a test well drilled near Brunswick, Ga., under the supervision of R. L. Wait, hydrochemical facies in a vertical section were as follows: calcium bicarbonate facies in upper 1,000 feet, brackish water of the sodium chloride facies in the next 330 feet, and magnesium sulfate facies in the lower 360 feet.

Preliminary results of laboratory studies by B. B. Hanshaw of the behavior of compacted clays as semipermeable or osmotic membranes indicated that they are capable of affecting the chemistry of subsurface waters and the fluid pressure. Ultrafiltration or salt filtering occurs when a saline solution is forced through compacted clay. Hanshaw suggests that where a pressure differential exists across a body of shale, this process may be effective in increasing the salinity on the high-pressure side of the shale. The ability of shale to act as an osmotic membrane could also be a factor in the occurrence of anomalously low fluid pressures in parts of some of the sedimentary basins of western conterminous United States and Canada.

Origin of minerals in natural water

Decrease in sulfate content of ground waters with increasing distance down-gradient from areas of hydrothermally altered rock in Truckee Meadows, Nev., has been observed by Philip Cohen (Art. 114). The change is referred to mixture of the sulfate waters from the altered-rock area with dilute water applied for irrigation on the Meadows. The sulfate in water near the bleached-rock zones is derived from the products of the alteration, rather than from gypsum contained in the alluvial materials.

A. R. Leonard and P. E. Ward (Art. 52) have shown that the water of salt springs in the Arkansas and Red River basins of western Oklahoma, Kansas, and Texas can be distinguished from oil-field brines on the basis of the Na/Cl ratio. Brine from salt springs has a ratio close to 62/100, whereas the ratio for connate oil-field brine is consistently less than 60/100 and averages about 50/100. The salt-bearing strata are in red beds of Permian age and occur in all units from the Wellington Formation to the Whitehorse Group.

In the Beaver Creek strip-mining area, Kentucky, G. W. Whetstone and J. J. Musser have found (Art. 53) that the aluminum content of surface waters is controlled by the pH of the waters in accord with theoretical considerations. The West Fork Cane Branch, having a median pH of 6.0, contains 0.0 to 0.2 ppm (parts per million) of aluminum. The Helton Branch, median pH 6.7, ranges from 0.0 to 0.4 ppm Al; but the Cane Branch, median pH 3.2, ranges from 0.0 to 85 ppm Al, and has a median Al content of 5.5 ppm. Sulfuric acid derived from weathering pyrite in the strip-mine waste dumps causes the low pH of Cane Branch. Ground waters in the region conform to the pattern set by the surface waters in content of Al relative to pH.

H. T. Mitten, C. H. Scott, and P. G. Rosene have found that although concentration of dissolved solids generally varies inversely with lake volume in any of the lakes in the Devils Lake chain in North Dakota, the percentage of equivalents per million of individual ions does not vary significantly. Water entering the lake chain is of the calcium carbonate type. In a downstream direction, a change from calcium-magnesium to sodium-potassium predominance, and from bicarbonate-carbonate to sulfate predominance was observed. In the last lake of the chain, precipitation of sodium sulfate causes an increase in the proportion of magnesium but little or no increase in calcium, and there is an increase in chloride plus fluoride and nitrate.

Water from nonthermal springs rising in granitic terrane of the Sierra Nevada, California and Nevada, is dominantly bicarbonate and has mixed cation contents. Breakdown of plagioclase and orthoclase feldspars provides early contents predominantly of sodium and potassium. With additional contact with the rocks, calcium and magnesium increase, presumably as the PCO_2 of the water diminishes through reaction with the minerals, and secondary carbonate minerals, more readily soluble, are attacked. Silica is abundantly available throughout the course traveled by the waters. J. H. Feth, C. E. Roberson, and W. L. Polzer, reporting the above, note that the chloride content is characteristically less than 1 ppm, and in half the samples it is less than the mean chloride content of snows earlier sampled and analyzed. Possibly anion sorption may remove small quantities of chloride from the circulating waters.

ORGANIC GEOCHEMISTRY

Organic content of rocks

Organic material derived from plant debris on the barrier bar of Choctawhatchee Bay on the northern Florida Gulf coast is carried down through the dune sand by natural waters and redeposited at the fresh water–salt water interface. The deposited material, termed "hasemanite" by earlier workers, was once thought to be a progenitor of asphalt and petroleum. Studies by V. E. Swanson have shown that the material has a low hydrogen and a high carboxyl content, and that it is not genetically related to petroleum.

The hydrogen content of the organic fraction of shale is suggested by I. A. Breger as a means of determining the area of maximum aquatic organic contribution in a basin. This in turn may indicate the most likely area for petroleum formation.

Soluble extracts from both the Pierre Shale and a Brazilian Precambrian phyllite studied by I. A. Breger appeared to contain long-chain unsaturated fatty acids, suggesting that certain basic marine biochemical processes may not have changed appreciably since the Precambrian.

Organic pollutants in water

The synthetic detergent alkylbenzenesulfonate (ABS) is removed from solution by adsorption on surfaces of quartz grains. C. H. Wayman (Art. 117) found that the amount adsorbed on the quartz is less than equivalent to a monomolecular layer of ABS when the surface area of the quartz is greater than 50 cm^2 per g and the concentration of ABS is less than 100 mg per liter.

Iron and manganese in water and plants

When aquatic plants form a dense cover over a water surface, they may prevent oxygen from going into solution in the water by excluding air. E. T. Oborn and J. D. Hem (1962) reported that redox potential decreased and iron content of water increased during the growing season in tanks where water-stargrass, parrotfeather, and associated floating vegetation were present.

Aquatic vegetation was found by Oborn to have a high manganese content, compared to corresponding parts of land plants.

SYNTHESIS OF GEOCHEMICAL DATA

Good progress was made on the revision of Clarke's "Data of Geochemistry." The revised edition will be published separately in 36 chapters as each is ready. Six chapters are now in press.

During the past fiscal year a unit in the Geological Survey was established to collate and synthesize the vast geochemical and geobotanical data being gathered by the Survey. D. F. Davidson is studying the feasibility of coding and retrieving geologic and geochemical data by machine. Work has consisted of establishing a workable code and a format of punch cards for sample description and storage of data for rocks, minerals, soils, waters, and plants.

Philip Bethke compiled a list of 200 best-available unit-cell dimensions for sulfide, sulfosalt, and related minerals. Where precise determinations have been reported by several laboratories, the agreement in reported values is usually very good. Bethke and Barbara Hammond have also determined precise cell dimensions for the following compounds: HgSe, HgTe, CdSe, CdTe, ZnTe, PbTe, PtS, and NiS_2.

DISTRIBUTION OF MINOR ELEMENTS

Beryllium in silicic volcanic rocks

R. R. Coats, P. R. Barnett, and N. M. Conklin have found that the beryllium content of glassy silicic volcanic rocks in the western conterminous United States ranges from 0 to 20 ppm. The median value is about 3.6 ppm, slightly less than the value found by other investigators for granitic rocks. There is a positive correlation of beryllium with fluorine in these rocks.

The higher beryllium concentrations are in a belt trending southwest from central Montana into northeastern Nevada and a belt in western New Mexico and central Colorado. Some rocks of high beryllium content have been found in the Big Bend region of Texas.

Heavy metals in shales

D. F. Davidson and H. W. Lakin (Art. 85) now have analytical data for the heavy-metal contents of marine-shale units from 15 geologic formations of the western conterminous United States. Data for six geologic formations were previously reported (Davidson and Lakin, 1961). Some samples contain as much as 1.5 percent zinc, 5 percent vanadium, 1 to 2 percent nickel, and 0.7 percent selenium. These metal contents are comparable to those of shale units considered "ore" in other parts of the world.

Of particular interest is the occurrence of approximately 5 ppm of tellurium in a sample of the so-called vanadiferous shale in the Phosphoria Formation of Wyoming. This is apparently the first time tellurium has been recognized in marine shales.

Abundance of scandium in volcanic rocks

Using Rittman's classification to determine the clan, V. C. Fryklund, Jr., and Michael Fleischer suggest the following scandium abundance figures: basalts, 38 ppm; andesites, 34 ppm; dacites, 21 ppm; rhyodacites, 14 ppm; quartz latites, 11 ppm; and rhyolites, 5 ppm. Using Poldervaart's suggested ratio of rock types,[67] they suggested a content of 30 ppm scandium in the earth's crust.

Rare earths in apatites

Z. S. Altschuler has studied marine-apatite mineral separates from Florida and Morocco phosphorites, including composite samples representing extensive deposits. Total rare earths ranged from 0.04 to 0.1 percent. The marine apatites from these platform phosphorites are characterized by the dominance of lanthanum in contrast to igneous and pegmatitic apatite, which generally contain Ce>Nd>La.

Thorium and uranium in some alkalic rocks from Virginia and Texas

Results of studies of the distribution of thorium and uranium in suites of alkalic rocks from Virginia and Texas by David Gottfried, Roosevelt Moore, and Alice Caemmerer (Art. 27) support the view of Phair [68] that those products of crystal fractionation notably enriched in these minor elements are distinguished by an extremely low content of CaO. These studies provide a

[67] Poldervaart, Arie, 1955, Chemistry of the earth's crust, *in* Crust of the earth: Geol. Soc. America. Spec. Paper 62. p. 155–169.

[68] Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colorado, and their bearing upon pitchblende deposition: U.S. Geol. Survey TEI–247, 53 p., issued by U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

chemical guide for possibly delineating areas of alkalic igneous rocks that would be significantly enriched in thorium and uranium.

ISOTOPE AND NUCLEAR STUDIES

Isotope and nuclear investigations provide new modes of attack on many geologic programs. Radioactivity-dating techniques provide a measure of geologic time. Deuterium analyses of natural waters and of water extracted from minerals and rocks permit new insight into hydrologic and petrologic problems. Lead isotopes provide data useful in interpreting the history of rocks, metamorphic and ore-deposition processes, and the evolution of the crust of the earth. Solid-state studies afford new approaches to mineralogy and to the study of phenomena such as luminescence and thermoluminescence. Current results of some studies are summarized below.

GEOCHRONOLOGY

Investigations in radioactivity dating are being continued with objectives of improving the basic techniques, extending their application to cover all of geologic time, and finding geologic explanations for apparently anomalous results. C^{14} age determinations provide a large amount of useful data for a variety of studies back to approximately 40,000 years B.P. (Before Present). The dating of deep-sea cores by the protactinium-thorium method now permits extension of age determinations back to approximately 200,000 years B.P., gradually closing the gap with the K–Ar, Rb–Sr, and U–Pb methods that range back to the oldest Precambrian.

Carbon-14 age determinations

A. T. Fernald (Art. 11) has used radiocarbon dates to limit the time of deposition of a widespread volcanic ash deposit in eastern Alaska to between 1,750 and 1,520 years B.P.

A report by W. G. Pierce (1961) describes permafrost and thaw depressions in a peat deposit in the Beartooth Mountains, Wyo. The age of the top of the peat according to a C^{14} age determination is 7,500 ±500 years B.P. A C^{14} age determination of a sample 11 feet lower stratigraphically has been reported by Meyer Rubin as 8,600 ±300 years B.P., thus indicating a rate of peat accumulation of about 1 foot per 100 years.

Radiocarbon dates (12,700 to 12,030 years B.P.) for buried peat at North Branch, Minn., indicate that the Mankato Stade preceded the Two Creeks Interstade rather than followed it. The study of the pollen in the peat, the areal geology, and the relation of the dates to those from the classical Midwest sections appear in an article by M. Fries, H. E. Wright, Jr., and M. Rubin (1961).

The sources of organic pollution in streams are being investigated by the C^{14} laboratory in cooperation with the Department of Health, Education, and Welfare. The method is similar to that used to detect the source of air pollution in smog studies. Samples of the organic pollutants are collected by passing thousands of gallons of the stream water through charcoal filters. The trapped material is removed by suitable solvents, and then its C^{14} activity is measured by the normal process. If the source of pollution is industrial waste, the sample has a very low C^{14} content. If the pollutant is from sewage, the activity is high, very close to that of present-day carbon. The method has been tested in several streams and one lake, and the results bear out anticipated pollution estimates.

To test the validity of C^{14} ages from snail shells, a tracer study using C^{14} labeled $CaCO_3$ was made by Meyer Rubin, U.S. Geological Survey, and R. C. Likens and E. G. Berry, National Institutes of Health. The labeled $CaCO_3$ was dusted on the food and added to the water in which the snails lived. The radioactivity of the new growth of the shell was measured, and it was found that up to 12 percent uptake of inorganic carbon is possible. This would yield an uncertainty of approximately 1,000 years in C^{14} ages from snails.

Protactinium–thorium dating

Studies in the dating of deep-sea cores have been continued in cooperation with the Marine Laboratory of the University of Miami. Results obtained by J. N. Rosholt, Jr., C. Emiliani, J. Geiss, F. F. Koczy, and P. J. Wangersky in the Pa^{231}/Th^{230} dating and O^{18}/O^{16} temperature analysis of core A 254–Beata Ridge C are in good agreement with earlier results[69] for other Caribbean cores.

Attempts to date European stalagmites and Key Largo limestones by the Pa^{231}/U, Th^{230}/U method were made by Rosholt in collaboration with P. Antal of the Marine Laboratory of the University of Miami. Results are in poor agreement with the ages estimated from stratigraphic relations.

Dating of uranium accumulation and migration

The method of dating the time of migration of uranium in sandstone deposits developed by J. N. Rosholt, Jr.,[70] has been extended to the study of uranium migration in sandstones above, at, and below the water table (Rosholt, 1961). A detailed study of the time of uranium migration in deposits of the Hulett Creek area, Wyoming, by C. S. Robinson and Rosholt (1961) indi-

[69] Rosholt, J. N., Jr., Emiliani, C., Geiss, J., Koczy, F. F., and Wangersky, P. J., 1961, Absolute dating of deep-sea cores by the Pa^{231}/Th^{230} method: Jour. Geology, v. 69, no. 2, p. 162–185.

[70] Rosholt, J. N., Jr., 1961, Late Pleistocene and Recent accumulation of uranium in ground water saturated sandstone deposits: Econ. Geology, v. 56, no. 2, p. 423–430.

cates that the first uranium deposition occurred more than 250,000 years ago for the deposits now at or above the water table. These deposits were oxidized, leached, and locally enriched 60,000 to 80,000 years ago. For the deposits below the water table the calculated ages indicate that the uranium accumulation probably did not begin before 180,000 years ago and has continued to the present.

Potassium-argon and rubidium-strontium dating

R. C. Pearson and Ogden Tweto (Art. 87) are using K-Ar age determinations to limit the time of faulting in the Leadville area, Colorado. Many faults can be dated geologically by their relations to Laramide porphyries. The latter have been dated by the K-Ar method.

Isotopic age studies of plutons in the central Sierra Nevada are being continued by R. W. Kistler and P. C. Bateman. K-Ar and Rb-Sr determinations range from 60 to 100 million years for 17 individual plutons.

Biotite from a phase of the Mountain City pluton in northern Nevada gives an apparent age of 81±5 m.y. by the K-Ar method, and zircon from the same rock is dated by the lead-alpha method at 70±20 m.y. This batholith has been correlated by earlier workers with the Idaho batholith for which Larsen and Schmidt [71] reported an average lead-alpha age of 108 m.y. Studies of the Mountain City batholith are being continued by R. R. Coats.

Rb-Sr dating of K-feldspars and of whole rock samples from the Minnesota River valley in Minnesota indicates an original age of 2.5 to 2.6 billion years for the Montevideo Granite Gneiss of Lund.[72] The K-Ar and Rb–Sr ages of 1.6 to 1.8 b.y. reported by Goldich and others [73] for mica samples from the gneiss are metamorphic ages. The Montevideo Granite Gneiss was intruded by small granite plutons. Rb-Sr ages on feldspar and on whole rock samples from one of these late granitic intrusives north of Granite Falls, Minn., are in good agreement with the previous K-Ar and Rb-Sr ages of 1.65 b.y. on biotite.

Lead-alpha age measurements

New lead-alpha ages on zircon from rocks collected in North and South Carolina are discussed by W. C. Overstreet, T. W. Stern, Charles Annell, and Harold Westley in Article 88 of this volume. The new results are in good agreement with data presented earlier by Overstreet and others (1961).

Lead-alpha ages on zircon are commonly in good agreement with K-Ar or Rb-Sr age determinations on micas or feldspars from the same rock; however, some sharply discordant ages are found. Lead-alpha ages for zircon are much greater than K-Ar ages for biotite in some rocks from the Leadville area, Colorado. R. C. Pearson, Ogden Tweto, T. W. Stern, and H. H. Thomas (Art. 87) conclude that the zircons in porphyry dike rocks of that area probably were derived from older rocks.

DEUTERIUM AND TRITIUM STUDIES

Deuterium in natural waters

Experimental data in a collaborative investigation by Irving Friedman, of the Geological Survey, and Lester Machta and Ralph Soller, of the U.S. Weather Bureau, show that deuterium and tritium in raindrops exchange rapidly with atmospheric moisture. Rain samples, therefore, may not always be representative of the cloud system, but more nearly of the lower 1,000 feet or less of atmosphere.

Samples of stratospheric water collected by airplane and balloon flights by the U.S. Air Force and Weather Bureau show a deuterium concentration that is too high for water derived by normal meteorological processes. The possibility that this stratospheric water forms by oxidation of atmospheric hydrogen gas is being investigated.

Deuterium analyses of individual raindrops collected by A. H. Woodcock of Woods Hole Oceanographic Institute show a relation between drop size and deuterium concentration, the small drops being enriched in deuterium as compared to the larger drops. This dependence of deuterium on drop size is in accordance with theory and experimental findings on the rate of isotopic equilibrium of water drops with their environment.

Deuterium analyses of two samples of Nile River water collected at Khartoum and at Cairo during high stage at both sites showed that less than 5 percent evaporation occurred in the 1,900 miles travel between the 2 cities.

One application of deuterium research in hydrology is the estimation of the rate of evaporation in saline lakes. The following equation describes the process:

$$R_iQ_i=R_oQ_o+R_vQ_v$$

where R_i=ratio deuterium to water, inflow;
Q_i=rate of inflow to lake;
R_o=ratio deuterium to water outflow;
Q_o=rate of outflow;
R_v=ratio deuterium to water in evaporate; and
Q_v=rate of evaporation.

This reduces to:

$$\frac{R_i}{R_L}=\alpha,$$

[71] Larsen, E. E., Jr., and Schmidt, R. G., 1958, A reconnaissance of the Idaho batholith and comparison with the southern California batholith: U.S. Geol. Survey Bull. 1070–A.

[72] Lund, E. H., 1956, Igneous and metamorphic rocks of the Minnesota River Valley: Geol. Soc. America Bull., v. 67, no. 11, pl. 2–3, p. 1482, 1484–1485.

[73] Goldich, S. S., Nier, A. O., Baadsgaard, H., Hoffman, J. H., and Krieger, H. W., 1961, The Precambrian geology and geochronology of Minnesota: Minnesota Geol. Survey Bull. 41.

Where R_L=ratio in lake if mixing is complete, when the lake has no outlet and losses to the ground are negligible. Values for α were found to fall within the range 0.90 to 0.94 for several lakes. Application of the deuterium-balance equation to Lake Tahoe indicated that only 38 percent of the inflow remained to escape as outflow. This conclusion is also supported by the salt balance for the lake. The hydrology of a series of lakes in central Washington which occupy the abandoned gorge of the Columbia River below Dry Falls was analyzed by the salt content and ΔD/H (deuterium to hydrogen) ratio of the waters. It was concluded that Deep Lake and Falls Lake are entirely fed by ground water, Alkali Lake which has a high deuterium content and relatively low salinity appears to be fed by surface flow. Lake Lenore and Soap Lake appear to be at least 95 percent ground water.

Deuterium analyses of ocean waters collected at three equatorial Atlantic stations were completed. Several distinct ocean-water masses characterized by their D/H ratio and salinity can be identified at each station.

Twenty-five samples of surface waters of the Pacific Ocean were analyzed for deuterium. These samples, together with others previously analyzed, show that there is less evaporation from the Pacific Ocean than from similar latitudes in the Atlantic.

A group of samples of water and ice were analyzed for D/H to determine the isotopic fractionation that occurs during the freezing of fresh water under a variety of natural conditions. The fractionations found were less than the theoretical and less than had been found for freezing of sea water.

Atmospheric hydrogen before explosion of a hydrogen-bomb and atmospheric methane after the explosion were analyzed by Hans Suess. The results show that atmospheric hydrogen before the explosion had a similar deuterium content to samples after the explosion, whereas the tritium content was somewhat lower before the explosion. Atmospheric methane also has a high tritium content.

A series of water samples obtained by drying small samples of cores from the preliminary test drilling at the Guadalupe and LaJolla sites of the Mohole project showed a depletion in deuterium relative to present ocean water, and that large variations in deuterium occur from sample to sample.

Deuterium analyses by Irving Friedman and Orn Gardarsson of over 150 water samples collected in Iceland at different seasons of the year from surface waters, rain, and boreholes in hot-spring areas indicate that the source water of adjacent boreholes can be quite different, and that the recharge area may be many tens of miles away. Source areas for some of the thermal waters may possibly be identified by deuterium data.

The water and deuterium in the phenocrysts of glassy silicic volcanic rocks from the Jemez Mountains, N. Mex., were studied by Friedman in cooperation with R. L. Smith. The water content of biotite ranges from 4.5 to 0.9 percent by weight, and that of hornblende, from 1.5 to 0.3 percent water. The relative deuterium content varies inversely with the water content. These data suggest a relation between water-vapor pressure in the melt and the total water and deuterium content of the biotite and hornblende. Light hydrogen is lost preferentially during cooling and crystallization of some lavas, causing the formation of oxybiotite and oxyhornblende and concentrating deuterium in the remaining hydroxyl in the minerals.

Biotites, hornblendes, and chlorites were separated from a suite of rocks from the southern California batholith and the relative deuterium content of their structural water determined. No relation was found between the silica content of the rock and the water content of the minerals. The relative deuterium concentration was found to increase as the silica content of the host rock decreased. Deuterium extracted from biotites and hornblendes of mafic inclusions found in the Bonsall Tonalite revealed that the water had not completely exchanged isotopically with the water of the enclosing tonalite.

Tritium in fallout

Tritium isotopic research conducted by L. L. Thatcher and coworkers has involved documentation of new tritium fallout resulting from the nuclear weapons test series of the Soviet Union in the fall of 1961. The previous test series was in the fall of 1958 so that the new tests provide a 3-year interval marker on the tritium time scale. This precisely known spacing of tritium atmospheric pulses with a quiescent period in between should be very useful in current and future ground-water-movement studies. The variation of average tritium concentration in precipitation, progressing inland from the coast, should be of great importance in the analysis of marine-moisture distribution over the continent of North America.

E. H. Walker reports that water with a high content of tritium resulting from nuclear tests (1954 and later) has moved a few miles into the basalt aquifer of the western Snake River Plain in Idaho from main sources of rechage such as streams and large irrigated tracts. The average velocity of ground-water movement through the aquifer is estimated to be about 1 mile a year. The water is stratified, and minor recharge from precipitation in the central parts of the plain has also raised the tritium content of the upper layers.

Tritium tracer studies, Lake McMillan, New Mexico

A hydrologic tracer study using artificially injected tritium was begun at Lake McMillan in New Mexico in

April 1961. Objectives of the project were threefold: estimation of the amount of leakage through solution holes in the lake bottom, measurement of the travel-time of leakage water from the lake to the suspected outlet in a springs area, and estimation of the geometry of the ground-water reservoir associated with the lake. The lake was dosed with 150 curies of tritiated water supplied by the Atomic Energy Commission. A criss-cross pattern of dispensing from a slowly moving boat was used to get relatively uniform distribution of the tritium and avoid the possibility of concentrated areas. Through the following 2 weeks more than 100 samples were taken at various depths and surface locations in the lake to follow the rate of mixing of the isotope.

The tracer was followed through the hydrologic system consisting of Lake McMillan, the Pecos River entering and issuing from the lake, the Southern Canal issuing from Lake Avalon, and associated springs and wells. The tritium tracer in the lake decreased from 2,000 T.U. (1 T.U. is equivalent to 1 tritium atom in 10^{18} atoms of protium) to 1,000 T.U. in 1 month and then decreased to 100 T.U. in the following 6 weeks. There was an accompanying rise of tritium in the Pecos south of McMillan and in the Southern Canal. In June and July the tritium peak passed through Twin Boil springs. Although it apparently did not appear in the other springs, the tritium rise in the Pecos seems to be associated with some underground channel that conducted the tracer into the river in the springs area. The tritium levels appeared to have reached equilibrium by the following year, indicating that the tracer had passed completely through the system. Hydrologic analysis of the data is now in progress.

Tritium tracer studies in ground water

Paul Jones and L. L. Thatcher have successfully used tritium tracing techniques to analyze the ground-water movement pattern in the National Reactor Test Site area in Idaho. The pattern indicates the areas subject to potential contamination by hazardous radioisotopes from underground disposal of the reactor wastes.

A study of ground-water movement in the area around Bellevue, Ohio, involves (a) the practical consideration of ground-water contamination by a sewage-disposal system that enters a limestone aquifer and (b) the theoretical consideration of ground-water movement rates in limestone. By means of tritium-fallout measurements it appears possible to estimate the time of movement from the Bellevue area to surrounding agricultural districts and thereby estimate the magnitude of sewage movement. Measurements at selected wells gave 95 T.U. from a depth of 90 feet and 9.4 T.U. from a depth of 185 feet. Both measurements reveal that at least part of the pumpage from these wells consists of water that fell as precipitation after the large H-bomb explosion of 1954, which indicates relatively rapid water movement in the limestone.

A study of temperature fluctuations in ground water of the Schenectady area, New York, was carried out by John Winslow, who interpreted the variations as indication of infiltration from the Mohawk River (Art. 111). The river water shows annual variations through a range of 45°F, and the ground water shows a decreasing annual temperature range as a function of distance from the river. This evidence of infiltration was later confirmed by tritium measurements, which indicated that the ground water contained a high proportion of recent water. Recharge from the Mohawk River appears to be the only possible explanation for the high tritium values in the ground water.

LEAD ISOTOPES

B. R. Doe in cooperation with S. R. Hart, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, has studied the effect of contact metamorphism by the Eldora Quartz Monzonite stock on the isotopic composition of lead in potassium feldspars of the Idaho Springs Formation near Boulder, Colo. It was shown that lead entered the feldspars of the contact zone to about 250 feet from the intrusion. The intrusion is about 8,000 feet across. In addition, it was conclusively shown that not all the lead added to the feldspars could have come from the stock. The source of lead was probably from rock immediately surrounding the potassium feldspar.

In collaboration with G. R. Tilton, of the Geophysical Laboratory, Carnegie Institution of Washington, Doe has studied the isotopic constitution of lead in potassium feldspars from charnokite from Shenandoah National Park, Va., and from the Appalachian Province approximately 100 miles northeast, near Baltimore. In potassium feldspar from the charnokite which was subjected to regional metamorphism about a billion years ago, the lead-isotope constitution is fairly uniform and yields Precambrian model lead ages. Near Baltimore, where severe metamorphism occurred 300–450 m.y. ago in addition to the billion-year event, the isotopic composition of lead in the feldspars ranges considerably, and the model lead ages generally are younger than in rocks at Shenandoah National Park. These results suggest that lead was added to the feldspars near Baltimore during the later metamorphism.

Regional variations in the abundance ratios of lead isotopes from galena deposits of the Eastern United States are being investigated by A. V. Heyl and M. R. Brock in collaboration with J. J. Warr and Maryse Delevaux. Data from the Wisconsin-Illinois-Iowa district show large ranges for the isotope ratios of lead. The preliminary results suggest systematic variations with a radial distribution from the center of the district outward.

SOLID-STATE STUDIES

Luminescence and thermoluminescence studies

Using a fast electronic system, P. Martinez and F. Senftle have completed a study on the decay time of alpha-particle pulses in cesium iodide. Three modes of decay have been observed in thallium-activated cesium iodide and two in the pure material. Low-temperature thermal de-excitation studies have also been made using alpha particles, X-rays, and ultra-violet light. The thermal de-excitation curves are different depending on whether the cesium iodide is activated with alpha particles or X-ray excitation. Spectral measurements of the emitted light are also being made. It is hoped that the combination of these several techniques will yield data which will aid in the interpretation of the basic luminescence mechanisms.

Magneto-acoustic studies

It is well known that the attenuation of ultrasonic waves in a metal is considerably enhanced if the specimen is in a transverse magnetic field. By adjusting the field strength and the wavelength, a resonance condition of maximum attenuation can be achieved from which the Fermi surface can be determined. A study of the Fermi surface of crystalline materials yields a measure of the band energies from which many physical properties such as light absorption can be computed. Such studies of several metals such as copper and silver have been successful, but owing to experimental difficulties nothing has been done on the alkali metals. A. F. Hoyte, in cooperation with Catholic University, is now undertaking magneto-acoustic studies on metallic potassium. A large ultrapure single crystal has been grown for the investigation.

Magnetic properties of ice

The study on the magnetic properties of ice by F. E. Senftle and A. N. Thorpe has been extended in an effort to determine the anomalous temperature-dependent diamagnetism previously reported. It was found that oxygen is chemically absorbed on the ice surface below a temperature of 150°K and that this was the cause of the increase in diamagnetism observed earlier. Special equipment designed to exclude oxygen from the system was constructed, and new magnetic measurements showed that ice has a diamagnetism of $(-0.683\pm0.001)\times 15^{6}$ emu per g from 77° K to 235° K.

A cell for fast freezing has been devised to make X-ray pattern studies down to 77°K. With the use of this technique it has been demonstrated that small amounts of organic substances such as alcohol retard the rate of crystallization of the ice to such an extent that "glassy" ice can be made by normal "slow" freezing methods. Further work in this direction is planned for hydrous minerals.

HYDRAULIC AND HYDROLOGIC STUDIES

Increasing demands for water for industrial, agricultural, and domestic uses have stimulated research in the problems of supply and movement of water, both on the surface and underground. Results of much of this research are reported in earlier sections of this chapter under the appropriate regional headings. The following section presents findings of more general application.

OPEN-CHANNEL HYDRAULICS AND FLUVIAL SEDIMENTS

Distribution of velocity

By laboratory study H. J. Tracy and C. M. Lester defined a central region of flow in a rectangular flume in which the traverse velocity gradient is zero and the vertical velocity distribution is proportional to the log of the distance from the channel bed. Within this zone of two dimensional flow, the "universal" constant in the Karman-Prandtl velocity equation varies with the aspect ratio of the channel if the usual assumption is made that the bed shear is equal to the product of the specific weight, depth, and slope of the fluid.

Dispersion in natural channels

R. G. Godfrey and B. J. Frederick conducted 11 dispersion tests in 5 reaches of natural channels and 1 canal using a line source injection of a radiotracer. The dispersion patterns were compared with the patterns predicted by the theroretical models previously developed by other investigators for one-dimensional flow. The theoretical models do not adequately describe the dispersal pattern, nor the dispersion coefficient in large open channels. The time-concentration distributions do not follow the normal law as predicted by theory, and are highly skewed. The dispersion coefficients are 2 to 30 times greater than expected from a theoretical one-dimensional model.

D. W. Hubbell and W. W. Sayre have conducted bed-material dispersion tests in a large laboratory flume and in a reach of a natural channel in Nebraska. Tentatively, it has been concluded that the distribution of particles dispersed from a plane source is a composite of individual distributions and that each individual distribution, which is for a narrow size range, can be described with the statistical function called the gamma distribution. In addition, the discharge of bed-material particles can be computed from measured distributions of tracer particles, provided the tracer particles have the same transport characteristics as the bed material and are dispersed from a plane source. Because of the relation between dispersion and transport, the prospects of determining dispersion distributions from known or independently computed transport rates are promising and depend on the extent to which parameters in the gamma distribution can be predicted.

Solution of unsteady-flow problems

S. E. Rantz (Art. 46) developed a coaxial correlation method to describe the momentary discharge of tide-affected streams. Discharges of the Sacramento River at Sacramento, Calif., computed by this method compare satisfactorily with the measured flow.

Measurement of water discharge and sediment transport

A control structure for the measurement of the water discharge and sediment transport in the Rio Grande Conveyance Channel near Bernardo, N. Mex., was designed on the basis of a model study by E. V. Richardson and D. D. Harris (Art. 175). The stage-discharge relation for the structure is unaffected by the sediment discharge or changes in bed configuration of the canal. The structure should be suitable for installation on other sand-bed streams to improve water and sediment discharge records.

The use of radioisotopes to measure water discharge by the dilution method was evaluated in laboratory tests by B. J. Frederick and others (Art. 176). Discharge through a pipe was measured by the dilution method, and volumetrically. The tests indicate that an accuracy of 1 percent can be attained by relative counting of the isotope concentrations in a standard volume.

Resistance to flow and sediment transport in alluvial channels

Flume studies of sand-bed channels, by D. B. Simons, E. V. Richardson, and W. L. Haushild, show that both physical size and fall velocity of bed material are important variables in the study of resistance to flow and sediment transport. Physical size is related to grain roughness, and fall velocity is related to form roughness and sediment transport. The relative roughness depends on the type of form roughness. Ripple amplitude is independent of depth, and the relative roughness decreases as depth increases. Dune amplitude tends to increase with depth but relative roughness does not change. Where the bed roughness is due to ripples and (or) dunes, if depth is corrected for the separation zones downstream of the ripples and dunes, a much more precise resistance to flow relation can be established. Gradation of bed material has a definite effect upon both resistance to flow and sediment transport. A bed material composed of a large range in sand sizes has a smaller resistance to flow and a higher transport rate than a bed material that has the same median diameter but only a small range in sizes. The study further indicates why the gradation of bed material of sand-bed streams is relatively constant.

Flow in the Rio Grande may be classed as lower regime flow over a dune bed configuration and upper regime flow over a plane bed, with a transition zone between where the bed configuration is unpredictable. C. F. Nordin, Jr., found that the transition from lower to upper flow regime may be abrupt at individual cross sections for the Rio Grande near Bernalillo, N. Mex., but the transition in terms of average flow conditions through a sufficiently long reach is gradual. The transition is effected by lateral nonuniformity of velocity and depth at a cross section and by nonuniformity longitudinally through the reach.

Various transport theories have been studied using both flume and field data. Current analyses made by D. B. Simons, E. V. Richardson, and W. L. Haushild indicate that several of the theories yield good results within the lower flow regime, but they require rather drastic modifications to extend their usefulness to the upper flow regime. In general, best results have been achieved with a modification of the Einstein bed-load function for sediment transport. Using this procedure a transport theory has evolved which yields good results for both laboratory and field conditions.

C. F. Nordin, Jr., and G. R. Dempster find that both vertical-velocity and suspended-sediment distribution are influenced by bed configuration for several reaches of the Rio Grande. Vertical-velocity distribution is more uniform for flow over a dune bed than for flow over a plane bed, while suspended-sediment distribution is more uniform in flow over a plane than in flow over a dune bed.

H. J. Koloseus and J. Davidian have shown that uniform open-channel flow is unstable at Froude numbers greater than about 1.6. The instability is characterized by roll waves on the water surface, and by an increase in energy loss as compared to flow at lower Froude numbers. The increase in energy loss has been defined as a function of the Froude number for flow over cubical roughness elements.

SURFACE-WATER HYDROLOGY

Surface-water hydrology is the study of the occurrence and variability of streamflow in relation to physiographic, geologic, and meteorologic factors. If the basic relations governing the occurrence and variability of streamflow can be defined, the runoff from ungaged areas can be predicted from physical and meteorologic factors alone, and the changes in runoff regimen related to changes in physical conditions can be forecast.

Distribution and characteristics of streamflow

Fluctuations of streamflow depend on the variations of precipitation and on geologic and topographic features that tend to delay runoff. In some basins, for example, the opportunity for infiltration and storage of water in the ground is so great that the effects of variations in precipitation do not appear as variations in streamflow for several months. One of the problems in defining streamflow characteristics is to separate basin effects from the effects of variations in precipitation so that short records can be used to estimate long-term expectancy.

Characteristics of streamflow are commonly affected by works of man that regulate or divert water after it reaches a stream channel. In some basins even the amount of runoff generated over an area is affected by changes in land use, such as urbanization. In other basins withdrawal of ground water affects the amount of flow that reaches stream channels. The flow of Kahaluu Stream, Oahu, Hawaii, for example, is shown by G. T. Hirashima (Art 108) to have been decreased 26 percent by the construction of Haiku tunnel 2½ miles away. In a similar study, S. E. Rantz (1961a) and (1962) [74] shows that although one spring in Santa Barbara County, Calif., ceased to flow after the construction of the Tecolote tunnel, the flow of other springs and streams in the area was not noticeably affected.

In some areas the most critical characteristic with regard to water supply is the amount of water that can be recovered either as streamflow or by ground-water discharge. For San Nicolas Island, Calif., for example, Walter Hofmann and W. C. Peterson determined from a study of precipitation and water losses that the amount of water that could be recovered annually ranges from 0.8 inch in the northeastern part of the island to 2.1 inches along the southern coast.

G. E. Harbeck, Jr., concluded from studies of thermal loading of the Holston River in Tennessee that a substantial amount of heat was conducted from the water into the stream bottom. In considering the interchange of energy by conduction between water surface and atmosphere in thermally loaded streams he concluded that the Bowen ratio concept is invalid for large air-water temperature differences and that a revision of the theory developed for thermal loading of streams appears desirable.

Magnitude and frequency of floods

Nationwide reports by the Geological Survey on magnitude and frequency of floods provide a basis for estimating the magnitude of floods of selected frequency, usually up to 50 years, at any site, gaged or not gaged. The reports contain descriptions and lists of peak stages and discharges for all gaging stations that are not materially affected by storage or diversions, and that have five or more years of flood record. The parts of the country discussed in these reports correspond to the drainage-basin subdivisions of the United States used by the Geological Survey.

Flood-inundation mapping

Flood-inundation maps showing the limits of past inundation, flood profiles of principal streams, stage-frequency relations, and descriptive text have been published for the following urban areas: Springfield, Newark, Fremont, Barberton, and Canton, Ohio; Harrisburg, Pa.; and Boulder, Colo. (Jenkins, C. T., 1961). (See "List of Publications" under entry "U.S. Geological Survey" for listing of Hydrologic Investigations Atlases for specific cities.)

Floods in the Southeastern States

Disastrous floods occurred in the Southeastern States during February–March 1961, when large streams produced rare record-breaking peaks and prolonged inundation, according to H. H. Barnes, Jr., and W. P. Somers.[75] J. D. Shell [76] reported record-breaking floods and extensive damage centered in Mississippi during December 1961.

Floods in Nevada

Unseasonally warm rains falling for several days on low-altitude (4,500–7,000 feet) snow resulted in record-breaking floods in northern Nevada during the period February 9–17, 1962, according to R. D. Lamke. Provisional data show that a series of peaks occurred on the main stem of the Humboldt River and a number of its tributaries. The peak (6,610 cfs) at the Palisade gaging station on the Humboldt River exceeded by 360 cfs the previous high recorded during the 55-year period of record. An unmeasured flood in 1910, however, may have produced a higher peak discharge.

An even greater peak discharge (10,400 cfs) was recorded at the gaging station at Devil's Gate on the North Fork of the Humboldt River. This peak exceeded the previous peak of 2,450 cfs recorded during a 27-year period for this station.

Severe property damage in the town of Battle Mountain resulted from a flood of the usually-dry lower Reese River. During the time of the peak discharge of nearly 5,000 cfs, several square miles of lowland were inundated. An unmeasured flood of approximately this same magnitude occurred in 1910.

Floods in Alaska

Streams in southeastern Alaska had an unusual number of flood peaks during 1961, according to R. E. Marsh. Record-breaking floods occurred on some

[74] Rantz, S. E., 1962, Flow of springs and small streams in the Tecolote Tunnel area of Santa Barbara County, California: U.S. Geol. Survey Water-Supply Paper 1619–R (In press).

[75] Barnes, H. H., Jr., and Somers, W. P., 1961, Floods of February–March 1961 in the Southeastern States: U.S. Geol. Survey Circ. 452.

[76] Shell, J. D., 1962, Floods of December 1961 in Mississippi and adjoining states: U.S. Geol. Survey Circ. 465.

streams in the Juneau area in August and in the Ketchikan area in October. No floods of any great magnitude were recorded in the central east-to-west belt across southeastern Alaska during either of these storm periods.

Peak flow resulting from the annual breakout of ice-dammed Lake George in south-central Alaska nearly equaled that of the record flood of 1958, although the volume of water in storage in the lake prior to the breakout was only about 80 percent of that stored in 1958. For the second successive year the breakout was caused by lake water overtopping the ice dams rather than by seeping through them.

Low flows and flow duration

Investigations by L. V. Page show that the average yields at low flow of streams in Louisiana range from 0.4 cfs per square mile in the eastern and west-central parts to zero in some other parts of the State.

Recent studies of low-flow characteristics of streams in the Mississippi Embayment in Mississippi and Alabama by H. G. Golden and J. F. Patterson show that the relatively high base flow of streams in the Fall Line Hills, which cut into the sand and gravel of the Cretaceous System, is sustained by discharge of ground water from the Tuscaloosa Group in the interstream areas. The highly permeable terrace deposits along the Black Warrior River contribute to the high base flows of streams in that area. In the extreme northern part of the Central Plateau some of the tributaries to the Tallahatchie River show median annual 7-day low flows exceeding 1.00 cfs per square mile, the highest index of any low-flow yield in the study area.

STATISTICAL METHODS

Use of correlation for augmenting autocorrelated streamflow information

N. C. Matalas, of the Geological Survey, and J. R. Rosenblatt, of the National Bureau of Standards, have investigated the use of regression analysis for improving the estimate of the mean for the dependent variable under the assumption that the dependent and the independent variables are nonrandom. The reliability of the mean based on observations and regression estimates relative to the mean based on observation varies directly with the crosscorrelation and indirectly with the autocorrelation of the variables. Large values of crosscorrelation can offset the loss of reliability due to large values of autocorrelation.

Information content of the mean

N. C. Matalas and W. B. Langbein have studied the information content of the mean for various types of hydrologic series by adopting a random series as the standard of information. The information content of the mean is a function of the intradependence of the observations; the greater this dependence, the lower is the information content. In the extreme case, however, as the intradependence approaches unity, its upper limit, the intradependence can be put to effective use. This situation arises when the outflow from a given system is a function of the inflows to the system over long periods of time. In such a case, relatively few observations can establish the mean.

MECHANICS OF FLOW THROUGH POROUS MEDIA

In connection with radioactive-waste disposal, W. N. Palmquist, Jr., and A. I. Johnson (Art. 119) studied, by means of a hydraulic model, the pattern of downward flow of liquid through the vadose zone beneath a simulated disposal pit. Their tests, which apply chiefly to arid areas, show that the amount of lateral spread of the liquid is largely dependent on the number and thickness of horizontally stratified layers with different permeability.

A. Nelson Sayre and W. O. Smith (Art. 118) have demonstrated by experiment that the concept of pellicular water masses retained on the surfaces of individual spheres after draining, as considered by some hydrologists, is not valid. Photographs of an arrangement of spheres, which was saturated and then drained by gravity, show no visible moisture except in the area where individual spheres are in contact.

J. M. Cahill and H. E. Skibitzke have used uncemented sand models to forecast ground-water movement in specific ground-water reservoirs, under proposed water development or waste-disposal practices. The sand model is dimensionally proportioned to the prototype system. Fluid is introduced and removed at rates scaled to represent rate of flow in the prototype. Colored inks or dyes are used to trace the fluid movement in selected parts of the flow system; and color time-lapse photography records the sequence of events displayed in the model.

At the request of the Scientific Adviser to the Secretary of the Interior, for the White House–Interior Panel on the water logging and salinity problem of West Pakistan, a theoretical study of ground-water movement in the Punjab Region of the Indus Basin of Pakistan was started by H. E. Skibitzke, R. H. Brown, and J. A. daCosta. They constructed an electrical analog model of a representative section of the aquifer in which measurements of electrical properties are made to represent hydraulic properties of the ground-water system as follows: electrical conductance represents transmissibility of the aquifer, capacitance represents the storage coefficient of the aquifer, voltage represents hydraulic pressure, and amperage represents flow of water. Various solutions to the field problems are being tested with the model.

J. E. Reed and M. S. Bedinger (1961) have shown that for steady-flow conditions in a finite water-table aquifer, the hydraulic head can be considered the sum of two components of head—the boundary component and accretion component. In an aquifer of given hydraulic characteristics, the boundary component is determined by the stream stage and areal shape of the aquifer; the accretion component of head is determined by vertical gain or loss of water to the aquifer and by the areal shape of the aquifer. The effect of changed stream stages on the water table may be obtained by adding the accretion component of head to a new boundary component of head caused by changed stream stages.

J. E. Reed and M. S. Bedinger (Art. 35) have reported that for steady-flow conditions in an extensive homogeneous aquifer, the head-change distribution produced by impoundment of a hydraulically connected stream, where the head change in the stream is linear, is defined by an equation derived from the Fourier integral.

In order to obtain information on the underground movement of water from the Lake McMillan reservoir, near Carlsbad, N. Mex., the reservoir water was "labeled" with 150 curies of tritium on April 24, 1961. The tritium was considered to be well mixed in the water by about May 4, 1961, when the tritium content, according to samples, was about 2,000 T.U. (1 T.U. is equivalent to 1 tritium atom in 10^{18} atoms of protium). From subsequent sampling, tracer tritium was first detected in one of the springs (Twin Boil Spring, one of a group of springs called Major Johnson Springs) in July 1961 and continued to show tracer tritium through the summer. Major Johnson Springs are 3 miles downstream from Lake McMillan. Tracer tritium, however, was not detected in any of the three intercept wells between Major Johnson Springs and Lake McMillan.

The tritium content of ground water in the Ogallala Formation in Lea County, N. Mex., indicates that water that collects in some, but not all, of the surface depressions percolates downward to the water table. Tritium analyses also show that recharge occurs in some places beneath the relatively level land away from the depressions.

FLOW IN THE UNSATURATED ZONE

An annotated bibliography on specific yield and related properties has been prepared by A. I. Johnson, D. A. Morris, and R. C. Prill.[77]

[77] Johnson, A. I., Morris, D. A., and Prill, R. C., 1960, Specific yield and related properties—an annotated bibliography, Part 1: U.S. Geol. Survey open-file report, 259 p.

Soil-moisture contents and soil temperatures observed by A. O. Waananen and C. T. Snyder in Columbus Salt Marsh, near Coaldale, Nev., show identifiable diurnal fluctuations in the 3½-foot-deep unsaturated zone. Water loss from the playa occurs principally by evapotranspiration from the bare soil and vegetation on the fringe of the playa. The diurnal changes in the soil-moisture profile and a comparison of the observed changes in soil-moisture content above the water table with pan-evaporation rates suggest that significant quantities of water moving upward from the water table are discharged by evaporation at the land surface.

R. W. Stallman designed a sensitive bridge for measuring the resistance of thermistors in the field. It was installed for test purposes at Elk City, Okla., for measuring the vertical distribution of temperature at shallow depths in a study of the movement of vapor and liquid in the unsaturated zone, and vertical components of flow in the upper part of the saturated zone.

Preliminary analysis of temperature profiles by R. W. Stallman and R. M. McCullough near Elk City, Okla., indicates that movement of moisture in the vapor phase may play a predominant role in the distribution of water relatively near the water table in the unsaturated zone. Significant dependence of moisture content on temperature, and perhaps on barometric pressure, voids the application of the specific-yield concept in microhydrology.

A nuclear soil-moisture meter has been applied by Walter Meyer to observe specific yield in pumping tests on unconfined aquifers near Garden City, Kans. Early test results indicate that specific yield is variable with time during pumping in a relatively thin aquifer having a transmissibility of about 120,000 gallons per day per square foot.

SALT WATER IN COASTAL AQUIFERS

H. R. Henry (Art. 34) has completed a preliminary mathematical analysis of the transitory movements of the salt-water front in an extensive artesian aquifer. The analysis indicates that a movement of the salt-water front caused by a change in sea level may continue for many thousands of years after the sea level has become essentially stable. The significance of this is that in extensive artesian aquifers, such as the Floridan aquifer of Florida and adjacent States, the salt water may still be moving slowly landward as a result of a rise in sea level that occurred in Pleistocene time.

N. J. Lusczynski (1961b) introduced the concept of environmental-water head in ground water of variable density. He defined the environmental-water head at a given point as the elevation of the water level in a well ending at this point and filled with water whose density corresponds at all depths with that of the water in the aquifer along a vertical line from the top of the zone of saturation to the given point. The concept is used as a basis for demonstrating the limitations of the Ghyben-Herzberg and Hubbert equations for the position of the interface between salt water and fresh water. The hydraulic gradient along the vertical is defined by differences in environment-water heads, and that along the horizontal by differences in pressure expressed in terms of heads of fresh water.

N. J. Lusczynski and W. V. Swarzenski report that in the Cedarhurst-Woodmere area of Nassau County, N.Y., the salty water at the bottom of a deep artesian aquifer advanced about 2,000 feet between 1952 and 1958. Elsewhere in southern Nassau County the salty water advanced more slowly. A seaward flow of salty water in the zone of diffusion probably retards the rate of advance.

From the results of test drilling, N. M. Perlmutter and F. A. DeLuca (1961) have found that in glacial-outwash deposits underlying till beneath Montauk Point, Long Island, N.Y., the top of the zone of diffusion ranged from sea level to about 130 feet below sea level. The water in the lower part of the zone of diffusion had a chloride content of as much as 11,300 parts per million. Because the occurrence of salty water at these shallow depths creates a danger of encroachment into existing ground-water supplies, it was suggested that the average rate of pumping from individual wells not exceed 35 gallons per minute.

Beneath the barrier beaches of southern Nassau County, N.Y., water having a chloride content of as much as 16,000 parts per million occurs not only in the permeable deposits but also in the clay deposits (Lusczynski and Swarzenski, 1961). At Atlantic Beach and Lido Beach, N.Y., three distinct bodies of salty water alternating with bodies of fresh water were identified by analyses of water extracted from core samples. The zones of diffusion are as much as 5 miles wide and range from 200 to 300 feet in thickness. The salty water has penetrated into most of the 180-foot thickness of the clay member of the Raritan Formation between Atlantic Beach and Lido Beach. The findings indicate that this salty water is probably moving very slowly downward toward the Lloyd Sand Member, which is presently a source of water supply.

G. W. Leve indicates that salt-water encroachment, as a result of heavy pumping in the vicinity of Fernandina and Jacksonville, Fla., is by lateral movement of water from mineralized zones within the major fresh-water aquifer rather than from mineralized zones lying beneath the fresh-water aquifer as previously suggested.

AQUIFER COMPACTION UNDER STRESS

In the Santa Clara Valley, Calif., aquifer compaction (and corresponding land-surface subsidence) due to artesian-pressure decline exceeded 10 feet from 1912 to 1960. Computations by J. H. Green (Art. 172) based on laboratory tests of core samples indicate that part of the area will subside another 3 to 4 feet eventually, if the artesian head were to remain at the 1960 level. Green has found that compaction reduces the porosity of the finer grained beds of the aquifer system, and that this reduction is greater near the top of the system than near the bottom. Because most of the compaction is inelastic, the coefficient of storage determined from subsidence during the first artesian-pressure decline greatly exceeds that determined from a subsequent decline through the same pressure range.

Analysis of precise leveling in the Memphis area, Tennessee, by G. H. Davis indicates that there has been no significant land subsidence due to decline of artesian pressure despite lowering of artesian head of as much as 100 feet before 1955. Subsidence on the order of 150 mm is indicated by bench marks on a railroad fill crossing the Mississippi bottoms west of Memphis, evidently due to settlement of the fill.

Analysis of consolidation and rebound tests of selected cores from unconsolidated water-bearing deposits in the San Joaquin and Santa Clara Valleys, Calif., by J. F. Poland, has indicated that porosity of the sediments tested increased about 5 percent on the average from the effective stress at the field-loaded condition to the unloaded condition. The depths of core holes ranges from 1,000 to 2,000 feet. Rebound of sands is less than that of clayey silt and silty clay.

Using highly sensitive liquid-level tiltmeters, F. S. Riley has observed that minute land-surface subsidence may begin to develop around a pumped artesian well immediately after discharge commences, but that the rate of development of the "cone of subsidence" lags appreciably behind the development of the cone of artesian-pressure decline. This suggests that much of the subsidence may be attributable to delayed leakage of water from the semipervious interbeds which compact as the water escapes. In terms of the experimentally determined compressibility of common rocks and minerals, however, the observed subsidence seems anomalously small, particularly if attributed to the entire thickness tapped by the well.

LIMNOLOGICAL STUDIES

Study of a small calcite-depositing stream in California by Ivan Barnes and K. V. Slack showed that: (1) dissolved-oxygen concentration and discharge varied inversely with air temperature; (2) the point at which the stream disappeared into the alluvium fluctuated 40 meters during one 24-hour period in May, but the dissolved-solids content showed that less than 10 percent of the water was lost by direct evaporation; (3) although photosynthesis by sessile algae and moss resulted in a net production of more than 3.3 g O_2 per m^2 per day during controlled experiments, the principal controls on dissolved-oxygen concentration were temperature and shallow, turbulent flow; (4) calcite precipitation increased downstream and reduced the habitats for invertebrate animals; and (5) spectrographic analysis of *Rivularia*, a calcite-encrusted bluegreen alga, detected Al, Fe, Ti, Mn, B, Ba, Cu, Li, and Sr.

Devils Lake in North Dakota is shallow and has a relatively large surface area. H. T. Mitten, C. H. Scott, and P. G. Rosene found that the temperature changes little either horizontally or vertically in the lake when it is not frozen. During the summer, a maximum difference of 5.5° F. was observed in about 15 feet of water on a calm day. Most of the temperature change occurred between the surface and middepth. During windy weather, however, the water in the lake rapidly becomes mixed, and there is only slight thermal stratification; a maximum difference of less than 1° F was observed between surface water and bottom water.

EVAPOTRANSPIRATION STUDIES

T. E. A. van Hylckama has been measuring the amount of water used by saltcedar (*Tamarix pentandra*) in six large evapotranspirometer tanks in Arizona. Outside the tanks, where the water table was 10 feet below the surface, no increase in branch length or development of new fronds was observed following a prolonged drought; but during the same period, branches grew as much as 3 inches per week and new fronds formed regularly on saltcedars within the tanks, where the water table was high. Likewise, in an area occasionally flooded by the Pecos River, E. R. Cox found that saltcedar is unable to take water directly from the water table if the depth to water exceeds about 13 feet.

Wide differences in the consumptive use of ground water by two species of phreatophytes, greasewood and willow, grown in evapotranspirometers in Nevada were noted by T. W. Robinson. The differences in evapotranspiration rates appear to result from differences in transpiration rates per unit of leaf surface and differences in total leaf surface per unit of ground area. In the 5-foot zone between the water table and the surface of these same tanks, diurnal variations in soil moisture amounting to about 1 percent of water by volume were measured by A. O. Waananen. These changes were mostly in the bottom half of the profile because of moisture withdrawals by the roots; changes near the surface were relatively small.

The top layer of ground water in the alluvium underlying the Rio Grande valley in Valencia County, N. Mex., has a high dissolved-solids content, according to F. B. Titus, Jr. The maximum specific conductance of water in this top 10-foot layer of high concentration is 4,080 micromhos, whereas water below that layer has a conductance of only 600 to 900 micromhos. The high concentration near the surface is attributed to the removal of water by evapotranspiration, leaving behind most of the dissolved solids.

R. A. Young and C. H. Carpenter have estimated that about 100,000 acre-feet of water is consumed annually by evapotranspiration from areas of phreatophyte growth in the central Sevier Valley in Utah, of which a substantial part could be salvaged if the water table were lowered by pumping from wells.

Evaporation from wet, salt-encrusted barren lands along the east shore of Great Salt Lake was only about 1 percent of pan evaporation. This was determined by J. H. Feth and R. J. Brown (Art. 40), in cooperation with the U.S. Bureau of Reclamation, by measuring the rate of accumulation of salt crust. This crust formed by evaporation of water from the brine with 93,000 ppm dissolved solids that moves upward, under artesian pressure, through the mud a few thousandths of a foot per day. Even so, the total discharge of water by leakage from the area (60,000 acres of mud flats) during the year was about 6,000 acre-feet of water.

GROUND-WATER OCCURRENCE IN LIMESTONE TERRANES

Studies in the Niagara Falls, N.Y., area by Richard H. Johnston (Art. 110) have indicated that ground water occurs principally in seven zones of open bedding joints in the Lockport Dolomite. The open bedding joints are developed in very thin-bedded units overlain by massive beds. These zones are much more permeable than the remainder of the formation and, in effect, constitute seven separate and distinct artesian aquifers.

Fresh water has been found to depths of more than 3,000 feet in limestone aquifers of the Arbuckle Group in the Arbuckle Mountain region of Oklahoma in a study by D. L. Hart, Jr. This condition is somewhat local in nature, being known only under about seven townships. The depth of fresh water in adjacent areas is normally only about 600 feet or less. It is believed that the abnormal depths of fresh water results from the relatively high permeability of the limestone and heavy recharge, which allows fresh water to circulate to greater depths to flush the mineralized water from the aquifer or to dilute it.

Largely on the basis of a field study in the Lebanon Valley in Pennsylvania, but checked with published data, Harold Meisler has formulated a new theoretical approach to limestone hydrology. It is a concept of dynamic equilibrium in which processes of solution, clay filling and collapse of solution openings, and lowering of the land surface are in a steady state of balance. Certain basic assumptions are required, but under a wide range of natural conditions where these may not be completely fulfilled the steady-state system appears to be maintained. The vertical distribution of secondarily developed porosity in a steady-state system is believed to have the following characteristics: (a) porosity is a function of depth below the land surface and does not vary with time; (b) the slope of the curve of porosity versus depth at any depth is proportional to the time rate of change of porosity (solution rate minus plugging rate) of a volume of rock at that depth—the constant of proportionality being the reciprocal of the rate of lowering of the land surface.

Using tritium for determining the age of ground water in the Roswell basin, New Mexico, James W. Hood has found that in all 37 samples analysed the water entered the ground-water reservoir in the 30-year period preceding 1959. Most samples had entered the aquifer between 1954 and 1959. This graphically demonstrates the rapidity of circulation of water in the cavernous limestone beds which are the principal aquifers of the area. These data also suggest that the specific yield of the San Andres Limestone is low and the system would be subject to decreasing yields during prolonged periods of drought.

Water was found in 1960 in limestone of late Paleozoic age at the margin of the Snake River Plain southeast of Twin Falls, Idaho. E. G. Crosthwaite reports that several wells tapping the limestone yield 1,500 to 3,000 gpm. Preliminary data suggest that the supply is limited.

GEOLOGY AND HYDROLOGY APPLIED TO PROBLEMS IN THE FIELD OF ENGINEERING

Various problems related to engineering are receiving attention from personnel of the Geological Survey. Important among these are problems in the selection of sites for and the construction of buildings, highways, dams, and tunnels. Investigations are being conducted concerning the feasibility of underground storage of fluids. The resumption of underground nuclear testing has involved the efforts of geologists and hydrologists in the many aspects of test-site selection and evaluation of the tests. The expanding population and modern technology have greatly increased problems dealing with water. Many of these, such as the following, are related to engineering: floods, erosion, pollution, evaporation suppression, artificial recharge of aquifers, and radioactive-waste disposal. Some examples of research related to such problems are presented in this section.

CONSTRUCTION PROBLEMS

Urban geology

A map by J. Schlocker (1962) showing bedrock contours and the depth to bedrock in selected borings within the San Francisco North quadrangle has been released for public inspection.

Continuing studies by D. R. Mullineaux in cooperation with the Municipality of Metropolitan Seattle have disclosed the presence of several ancient landslides along the route of a major sewage-disposal system. As a result, a longer tunnel will be driven, avoiding the slides, rather than the previously planned combination of short tunnel and trenches.

Detailed geologic mapping in the southern part of the Malibu Beach and Point Dume quadrangles, California, done by J. E. Schoellhamer and R. F. Yerkes in cooperation with the County of Los Angeles, has shown that the area is traversed by a steeply dipping strike-slip fault, flanked by older low-angle thrust faults. These faults make up an east-trending zone about 1 mile wide that parallels the Pacific coast along the south flank of the central Santa Monica Mountains. Numerous landslides in sedimentary and igneous rocks chiefly of Miocene age have been recognized along this zone. The delineation of these on geologic maps (Schoellhamer and Yerkes, 1961) is proving valuable in the planning for land development and use in this rapidly expanding urban area.

At the request of the Federal Housing Authority, M. G. Bonilla and G. O. Gates investigated earthquake hazards to structures in the marshlands on the southwest side of San Francisco Bay. In common with other marshlands around the bay, the area will be subject to ground motion of large amplitude and long duration during future strong earthquakes that originate on the San Andreas or Hayward faults. The studies indicate that further research is needed on the possible effects of earthquakes on San Francisco Bay sediments. Specific problems include whether failure by lateral spreading can be induced by seismic forces acting on bay deposits containing thin beds of sand or silt; whether subsidence will occur by compaction or flow of sand beds; whether the sensitivity of the bay mud has been increased locally as the result of leaking by fresh-water aquifers and, if so, how the mud will react under seismic stress.

Highway geology in Alaska

Possible routes suitable for the construction of a road from the vicinity of Talkeetna in the Susitna Valley, to McGrath were investigated by F. R. Weber (1961). The road would go over the Alaska Range not far from Mount McKinley through rugged mountain terrain with narrow passes subject to landslides and avalanches, and would cross many tumultuous mountain rivers. In the lower country there are poorly drained areas and some sections subject to the destructive effects of perennially frozen ground and to intense seasonal frost action.

Harold D. Roberts tunnel, Colorado

As a result of the engineering-geology investigations of the Harold D. Roberts tunnel, Colorado, several geologic factors of regional importance have been determined. E. E. Wahlstrom has concluded from structural analyses of the geology of the western part of the tunnel that the Williams Range thrust fault, a major structural element on the west side of the Front Range, is a gravity fault. From an analysis of the geology of the eastern part of the tunnel, which is in Precambrian rocks, L. A. Warner has established that the metasediments were subjected to two major periods of Precambrian deformation, which is in agreement with the findings of other workers in the Front Range. Surface mapping along the line of the tunnel by C. S. Robinson has shown that the emplacement at depth of the Tertiary Montezuma stock was in part controlled by a preexisting shear zone, probably of Precambrian age.

L. A. Warner has used such geologic features as rock type, foliation, and the attitude and density of joints and faults to derive a rock-competency factor that can be directly related to the rate of progress and the amount of support required in tunnel excavation. E. E. Wahlstrom has compiled, for some of the western part of the tunnel, the overbreak during tunneling operations as related to the rock type and structural features. This information indicates how drilling patterns may by modified to reduce the amount of overbreak, and consequently the amount of cement for lining a tunnel. Preliminary results of laboratory swell-pressure tests on fault gouge from the tunnel indicate that there is a direct relation between the swell pressure and the amount of steel required for support, and that probably the swell pressure is related to the type of rock that the faults cut. Thus, predictions as to the probable pressures perhaps may be made on the basis of surface geologic mapping.

One of the most significant of the engineering-geology results to date is a preliminary comparison of the surface and underground geology. From this it has been possible to determine the appropriate scale of surface mapping, width of area to be mapped, and the type of features to be observed in order to predict accurately on a statistical basis the geologic conditions at depth of a proposed underground opening.

Underground air storage

Site selection and construction of a pilot underground high-pressure air-storage chamber for the Pluto nuclear reactor at the Nevada Test Site has been aided by field and laboratory studies of the Geological Survey. These studies have shown that the rocks are dacite porphyry that has been highly jointed and fractured. Weathering and hydrothermal alteration have been most active along these fractures and have created local variations in the physical and chemical characteristics of the rock. Joints are locally sealed by calcite, iron oxides, and clay, but some of the fractures are open. The clay is montmorillonite and fills fractures that range in size from minute cracks to regional joints. The site selected for the pilot chamber was near that test hole at which the rocks tested were stronger and were least variable in strength. The rocks are as highly fractured at the selected site as elsewhere. Structural analysis and engineering laboratory tests on the rocks have influenced the design of the chamber and the mining methods. The design has been altered to compensate for the highly jointed and variable physical nature of the rock, and it has been suggested that all vertical walls be supported during mining to compensate for squeezing that may result from the high swelling capacity of the clays and the blocky and seamy properties of the rock.

Subsidence

In the San Joaquin Valley in California, subsidence has accelerated or expanded in response to increase in ground-water withdrawals and decline of artesian head caused by 3 years of subnormal precipitation and runoff. Releveling by the U.S. Coast and Geodetic Survey early in 1962 shows that in the Arvin-Maricopa area south of Bakersfield subsidence since 1959 has affected about 400 square miles or about twice as large an area as was subsiding from 1957 to 1959. The maximum rate is 0.5 foot per year. In the Tulare-Wasco area, north of Bakersfield, at least 800 square miles of land is subsiding at rates up to 0.7 foot per year. B. E. Lofgren has found that 300 square miles of irrigated land that had been relatively stable for several years prior to 1959 is again subsiding at rates of as much as 0.1 foot per year.

Subsidence is reported in several areas of intensive pumping of ground water in Arizona. In the Eloy area, southeast of Phoenix, releveling by the Coast and Geodetic Survey indicates maximum subsidence of about 5 feet from 1952 to 1960, 1 mile south of Eloy.

ENGINEERING PROBLEMS RELATED TO ROCK FAILURE

Two maps showing the structure, lithology, and topography of the Sunnyside No. 1 coal mine area, Carbon County, Utah, have been prepared by F. W. Osterwald (1962a) as part of continuing research on the geologic factors that influence coal-mine bumps. Underground mapping in the Sunnyside No. 1 mine indicates that some observable geologic features in the mine may be related directly or indirectly to bumps, and that other features may be used to infer stress distribution around workings that will aid in design of roof-support measures (Osterwald, 1962b).

Detailed study of bump areas and roof caves in the Sunnyside district revealed a correlation of roof, rib, and floor failures with lithology. Numerous shear fractures that curve into ribs and increase in dip downward are formed where coal moves into workings by slipping along a roof of shale or thin-bedded siltstone. Ribs are bulged and buckled where coal adheres to sandstone or coarse-grained siltstone in roofs and floors. Thin-bedded rocks in floors and roofs are bent into anticlines and synclines respectively. Roofs containing thick sandstone channels may cave, failing along shear fractures that decrease in dip downward because of high lateral compressive stress.

Roofs of thin-bedded siltstone and shale may fail along curved fractures similar to those formed during bumps. Siltstone or sandstone roofs containing sand grains that are separated by silt or clay shear easily, causing rib failures similar to those at places where the coal moves laterally beneath the roof. Correlation of the different types of rib, roof, and floor failure with lithology may enable engineers to take advantage of such geologic features in design of roof supports and mine layouts ahead of mining.

EROSION

Urban growth and sediment discharge

A study by F. J. Keller (Art. 113) on the effects of urban growth on sediment discharge in the Northwest Branch of the Anacostia River, Md., has shown that the suspended-sediment concentrations are as much as six times higher and persist for longer durations in water draining from urban-growth lands than in water draining from rural lands.

Coastal erosion

C. A. Kaye reports that a steep sea cliff on a drumlin island (Long Island) in Boston harbor, has been receding at an average rate of 0.3 feet per year during the course of 3½ years of measurements. The cliff is cut in compact oxidized till of early Wisconsin (Iowan?) age and stands 45 feet high at the maximum, with a slope of about 57°. Most of the erosion is the result of rilling by rainwash in the summer and the sloughing off of water-saturated material in early spring as the frozen layer melts. Wave erosion occurs only during high-tide storms, which generally are barely capable of washing away the talus that accumulates at the toe of the cliff between storms.

Intertidal erosion of a hard gabbro diorite at Nahant, Mass., has been measured by C. A. Kaye for a period of nearly 4 years. Here the erosional rate is variable, depending on inclination of surface and frequency of storm waves. A maximum erosional rate of 0.15 inches per year and a minimum rate of 0.01 inches per year were recorded. Most of this erosion is the result of pebble grinding.

A reconnaissance study of the coasts of Georgia and northern Florida made by C. A. Kaye for the U.S. Study Commission, Southeast River Basin, showed that the coast could be subdivided into erosional and depositional units. Criteria were recognized for identifying stable shores, mobile shores, shores of net retreat, and shores of net advance. Relatively stable shores, such as that of the long barrier beach of western Florida, are characterized by large dune fields or high foredunes. Shores that have undergone a net retreat during the present sea-level stand, such as those in the vicinity of Panama City and along several of the sea islands of the Georgia coast, are cliffed into higher Pleistocene terraces. A shore of steady advance is the almost waveless marsh shore of northwest Florida. Highly mobile shores, such as those along most of the coast of Georgia, characterized by alternating intervals of erosion and deposition but representing a net shore advance, can be recognized by the series of old beach ridges in the coastal belt. The study also brought out the importance of large sand-circulation cells fronting each of the sea islands of Georgia as factors controlling erosion and deposition.

GEOLOGIC STUDIES FOR DEFENSE AND PEACEFUL USES OF ATOMIC ENERGY

The underground testing and experimentation of nuclear devices and the generation of power by nuclear reactors releases radioactive products to the geologic and hydrologic environments. To safeguard the public welfare, the distribution, movement, and concentration of these products must be determined and the potential danger evaluated. Foremost in such a study is the definition of the environment of underground test and reactor sites. Since 1955 the Geological Survey has provided geologic and hydrologic data and evaluations of these data for the Atomic Energy Commission testing facility at the Nevada Test Site and at sites of the Plowshare experiments in other parts of the United

States. During 1961, this phase of its work was intensified, in part because of the resumption of nuclear testing by the United States and in part by an increased rate of preparation for tests of various peaceful applications of nuclear explosions and the application of nuclear energy to space programs.

Geology and hydrology related to underground nuclear tests, Nevada Test Site

Detailed geologic mapping of the entire Nevada Test Site, needed for all purposes from site selection to an understanding of the ultimate capability of the test site for testing purposes, continued at an accelerated rate. Maps of three 7½-minute quadrangles and of two 15-minute quadrangles were released during the year (Barnes, Houser, and Poole, 1961; Orkild, 1961; Orkild and Pomeroy, 1961; Hinrichs and Gibbons, 1962).

Geologic mapping at the Nevada Test Site and reconnaissance of some of the surrounding area shows that the Oak Spring geologic unit comprises at least 6 lithogenetic units and more than 30 mappable lithologic units. Because of diversity in composition, mode of deposition, and source areas of these units, the Oak Spring has been raised to the rank of group (F. G. Poole and F. A. McKeown, Art. 80), parts of which have been subdivided into the Indian Wash Formation and the overlying Piapi Canyon Formation. The group, with an aggregate thickness in excess of 10,000 feet, consists of tuffaceous sedimentary rocks, andesitic flows and flow breccias, simple and compound cooling units of multiple flows of rhyolitic nonwelded and welded tuff, and associated ash-fall tuffs. It also includes complexly intercalated rhyolite lava flows and intrusives, basalt flows, tuffaceous caldera alluvial fill, and relatively thin simple cooling units of nonwelded and welded tuffs. At least three source areas for the volcanics of the Oak Spring Group seem to be indicated: the Timber Mountain area west of the Nevada Test Site, where evidence suggests a collapsed caldera; an area west of Frenchman Flat, near Cane Spring; and the Kawitch Valley region, now largely buried beneath valley fill, north of the test site. New paleontologic and geomorphologic evidence indicates that the Oak Spring Group ranges in age from Eocene to Pliocene or younger.

Significant post-Tertiary faults, recognized as the result of recent mapping, are tens of miles long and have several thousands of feet of left lateral movement. These trend north to northeast and appear to terminate south of the test site in a zone that may be a northwestern extension of the Las Vegas shear zone. Recent mapping has also shown that thrust faults are more common than previously known, and may be an important controlling factor in ground-water movement.

Mapping and stratigraphic studies of the Cambrian rocks have resulted in correlating a part of the section with the Carrara Formation (Barnes and others, Art. 127) and in recognizing the Johnnie Formation east of Yucca Flat.

Regional gravity data have defined the configuration of the buried Paleozoic bedrock surface in the major valleys at the Nevada Test Site and surrounding region. Within the test site, maximum depth to bedrock under Yucca Valley is 4,700 feet, under Frenchman Valley it is 4,500 feet, and in Jackass Flats it is 3,000 feet. The depth to bedrock in valleys adjacent to the test site ranges from 3,000 to more than 4,000 feet but generally from 3,000 to 3,500 feet. For the valleys within the Nevada Test Site, gravity data have aided in the definition of through-going faults that have displaced the Paleozoic rocks. Most of these faults have normal displacements and trend northeast.

Parts of the Oak Spring Group, much of which is a desirable medium for underground tests, have been found by W. J. Dempsey to have strong remanent magnetization. Large negative magnetic anomalies are doubtless caused by some member with reverse remanent magnetism. A sampling program now underway should give more information on the magnetic properties of these rocks and lead to better understanding of subsurface relations.

Except for one test in salt in New Mexico (Project GNOME, described below) and one test in granite at the Nevada Test Site, all underground nuclear tests by the Atomic Energy Commission have been at the Nevada Test Site in tuff and alluvium.

The bulk physical and chemical nature of the enclosing rocks necessarily forms a basis for prediction and evaluation of the geologic effects of underground nuclear explosions. Geologic studies in Yucca Valley have enabled the preparation of structure and isopach maps of the alluvium, the principal testing medium in this area. Laboratory studies correlated in part with interpretation of geophysical logs were completed to aid in defining the in-situ properties of the medium. Such data have proved useful in evaluating the capability of continued underground-testing programs for the whole of Yucca Valley. Similar geological and laboratory studies were conducted for the test sites in granite (Houser, 1961; Houser, Davis, and Emerick, 1961; and Allingham and Zietz, 1962) and tuff (Hazelwood, 1961; Emerick and Dickey, 1962; and Emerick and Bunker, 1962).

Hydrologic investigations at the Nevada Test Site have been enlarged in scope to obtain a more thorough understanding of regional ground-water flow so that the possibility of contamination of off-site water supplies by underground nuclear explosions can be evaluated adequately. Early studies emphasized the movement of water in the alluvium, which has a maximum known thickness of 1,870 feet, and in the underlying tuff of the Oak Spring Group. Most of the tuff is underlain by limestones and dolomites of Paleozoic age; the hydraulic head is lower in the Paleozoic rocks than in the tuff, which indicates a downward movement of water from the tuff. S. L. Schoff and I. J. Winograd (1962) have shown that at some places the Paleozoic rocks are more permeable than the tuff and that water may travel laterally through these carbonate rocks.

During 1962, emphasis was on deep-test drilling in the Paleozoic rocks; the objective was to test enough sites so that the general features of the hydrologic system could be determined without an excessive number of test wells and an unnecessary amount of detail.

I. J. Winograd (1962a, b) points out that ground water in the alluvium and tuff is semiperched with respect to water in the underlying and locally more permeable Paleozoic carbonate strata. Three intermontane basins at the Nevada Test Site—Yucca, Frenchman, and Jackass Flats—appear to be hydraulically connected through intensely jointed and faulted zones in the carbonate rocks. Evidence of this connection is the nearly identical altitudes of piezometric surfaces, the permeability of Paleozoic rocks, and data from adjacent areas. Winograd suggests that water from these basins may discharge eventually in Ash Meadows, 25 to 30 miles southwest of the site, or in Death Valley, 40 to 45 miles farther southwest.

J. E. Moore (1961) compiled logs of water wells at the Nevada Test Site which had not been published. These logs and related hydrologic data on 18 wells drilled prior to 1960 will supplement future interpretative reports.

Reactor development

Static tests of certain nuclear reactors that are under development for use in the space program call for storage of large quantities of air under high pressures. This requirement has led to a novel application of geology to engineering—investigation of the feasibility of air storage below ground, either in excavated and lined cavities or in naturally or artifically permeable rocks. Detailed geologic mapping and vertical-resistivity profiling techniques established the suitability of a site for a planned experiment, reducing the cost and time needed for more definitive exploratory methods. Moreover, in-situ and laboratory analyses of the rocks have provided the basic parameters on which the design for an air chamber has been based.

Peaceful uses and detection of nuclear explosions

In addition to investigations of sites for underground tests and reactor development at the Nevada Test Site, the Geological Survey is involved in a variety of programs elsewhere that are aimed either at peaceful applications of nuclear explosions (the PLOWSHARE program) or at detection of nuclear explosions (the VELA program).

One unexpected byproduct of underground tests at the Nevada Test Site is the observation that moderately low yield contained explosions in alluvium result in large surface depressions, or sinks. The feasibility of developing harbors by creation of such sinks, or of preconsolidating alluvium by contained nuclear explosions in advance of construction, is suggested by F. N. Houser and E. B. Eckel (Art. 66).

Project GNOME

Project GNOME, the first experiment designed to explore peaceful uses of nuclear explosions, was a 5–KT nuclear device, detonated in salt beds of the Permian Salado Formation at a site selected by the Geological Survey near Carlsbad, N. Mex. The Survey provided many of the basic geologic and geophysical data required to define the preshot physical and geologic characteristics of the salt and other rocks affected by the explosion, as well as preshot and postshot information regarding ground-water conditions.

Detailed geologic mapping and lithologic descriptions of drill cores enabled engineers to predict conditions that would be encountered in construction of the 1,200-foot shaft and the 1,100-foot drift. Survey geologists who were logging, sampling, and photographing the rocks in the shaft and mapping the drift provided on-the-spot advice to the engineers on geologic and hydrologic problems during mining and construction.

Four hydrologic test holes were monitored at distances of 2,000 feet southwest, 3,150 feet west, 4,950 feet west, and 11,000 feet southwest of ground zero. These wells had already provided information on the subsurface hydrologic characteristics of the water overlying the Salado salt. At the time of the explosion the water level in the nearest well rose 3.97 feet almost immediately, and in the next nearest well it rose 2.20 feet. The rise in the two more distant wells is not known because the automatic gages were rendered inoperable by the ground shock. Within 12 hours the water levels had subsided to preshot levels. These and other data indicate that no appreciable water is leaking from or into the aquifer at the GNOME site. Moreover, radioactivity measurements made in water wells and other holes 3 weeks after the explosion indicate no increase in radioactivity in the aquifers. Results of the Survey's studies for Project GNOME are reported by J. B. Cooper and others (1962a).

Project CHARIOT

Project CHARIOT is a proposed experiment to create an excavation on the coast of northwestern Alaska by means of nuclear explosions. Recent Geological Survey investigations have been directed toward refining geologic, hydrologic, oceanographic, and geophysical data obtained in prior years (see, for example, Kachadoorian, 1961 a, b), and toward possible effects of fallout.

Distribution coefficients for carrier-free cesium, strontium, and iodine were determined on 17 samples of soil and rock from the CHARIOT site by J. H. Baker and W. A. Beetem. High-percentage uptake of these ions was measured, with strontium adsorption found to be related to the concentration of calcium and magnesium and iodine adsorption related to the amount of organic matter. No direct relation between cesium uptake and kind of soil or rock was noted.

Appraisal of the possibility of fission products entering streams and other natural waters is an important consideration in determining the feasibility of the CHARIOT experiment. The probable concentration of radioactive nuclides that would enter nearby waters under a variety of assumed conditions was studied by A. M. Piper. He estimates that, according to season and fallout pattern, part of the dissolved fission products would become fixed on earth materials and vegetation. The unfixed fission products would remain in solution in the surface waters. Their concentration in these waters would be greatest if fallout took place on saturated tundra just before freezeup and least with fallout on dry tundra followed by heavy precipitation.

Project SHOAL

The Atomic Energy Commission requested the Geological Survey to advise in the selection of a suitable site for Project SHOAL, a proposed underground nuclear detonation in either granitic rock or volcanic tuff and in an active earthquake area. The primary objective of the proposed Shoal experiment is to compare the seismic energy propagated from an underground nuclear explosion with that generated from a natural earthquake.

Earthquake records since 1945 were compiled by W. S. Twenhofel, R. A. Black, and D. F. Balsinger (1961) for all active seismic areas in the conterminous United States, and the geology and hydrology of the more seismic areas were further evaluated to determine their suitability for the experiment. Promising sites were inspected and evaluated in the field.

The site recommended for Project SHOAL is the northern Sand Spring Range, about 30 miles southeast of Fallon, Churchill County, Nev.; it has received approval by the Atomic Energy Commission and was publicly announced late in 1961 (Twenhofel, Moore, and Black, 1961). The Geological Survey has planned and recommended a program for further exploratory drilling and appraisal of the site.

Project GROUNDHOG

The Geological Survey was asked by the Defense Atomic Support Agency, Department of Defense, to advise on the selection of sites in the conterminous Western United States that would be suitable for chemical explosions underground in a variety of geologic environments. Sites were needed in limestone, sandstone, granite, volcanic tuff, and salt, as well as in two active earthquake areas. Following field and literature study by L. M. Gard, the Geological Survey recommended sites for each of these geological environments.

Project DRIBBLE

Project DRIBBLE is a planned series of nuclear tests in manmade cavities in salt, to determine the effect of decoupling on the detectability of underground explosions. The Tatum salt dome in Lamar County, Miss., has been selected for the site and has been the subject of intensive hydrologic, geologic, and geophysical study by the Geological Survey on behalf of the Atomic Energy Commission. Whereas most previous studies of salt domes have been confined to the rocks above them (for petroleum or sulfur resources), or to those around the domes at great depths (for petroleum resources), Project DRIBBLE is yielding detailed knowledge of the shape and character of the salt in the upper part of the dome itself. The salt consists of nearly vertical beds of clear halite, alternating with cloudy beds of anhydrite-bearing salt. The 600-foot-thick caprock consists of an upper 150-foot zone of cavernous limestone and a lower 450-foot zone of massive anhydrite. Hydrologic studies show that the aquifers around and above the dome are capable of producing prolific water supplies if needed to leach a cavern in the salt.

Geophysical studies of the rocks in southern Mississippi show that alternating zones with high and low seismic velocity are present in the upper Tertiary rocks; the underlying Cretaceous rocks are chiefly high velocity. These results show that the dome is of such size, shape, and structure as to be suitable for moderately intense nuclear tests.

ANALYSIS OF HYDROLOGIC DATA

Analysis of the large amount of raw data collected during hydrologic studies permits predictions of both high- and low-water flow conditions and may enable forecasting the effects of such activities as water-reservoir development, irrigation, and urbanization. The findings reported below concern a few specific applications of such analyses; other are reported elsewhere in this chapter under various hydrologic-studies headings.

Estimating long-term runoff from short-term records

W. S. Eisenlohr, Jr., has developed a procedure for estimating the runoff for a base period of many years from a short-term record, provided that sufficient gaging-station records are available to define a regional cumulative distribution of total runoff for the base period (Art. 173). A table of regional cumulative yearly runoff in percent of the total runoff for the base period furnishes factors for computing base-period runoff from a short-term record.

Extending streamflow data by using precipitation records

R. O. R. Martin has found, from a study of 3 pairs of concurrent 30-year streamflow records, that the standard error of estimate of monthly streamflow can be significantly reduced by including precipitation difference as a parameter in the regression between concurrent monthly streamflows at pairs of stations. The optimum length of record for definition of the regression was found to be 15 years.

Floods

Research in the hydrology of floods involves the study of factors responsible for the variability of flood occurrence and the relative importance of such factors. Such studies generally have been based on field data. The limitations of uncontrolled field data, however, have led to current studies of synthetic flood hydrology by electronic-analog methods.

M. A. Benson [78] has defined relations between flood peaks of various recurrence intervals and watershed and climatic characteristics, in a humid region. Similar studies relating to a semiarid region have also recently been completed by Benson.

In Michigan, S. W. Wiitala (1961) has studied the effect of urbanization on runoff by use of records of two adjacent small drainage areas, one urbanized, the other not. Indications are that in the urbanized watershed the lag time has been reduced to about one-third of the natural value and the peak discharge has been increased by two to three times, though no change can be detected in the total runoff. F. F. LeFever reports somewhat similar results for two streams in Nebraska. Urbanization in the basin of East Meadow Brook in Nassau County on Long Island, N.Y., is shown by R. M. Sawyer (1962a) to have more than doubled the amount of direct runoff so that it now averages about 17 percent of the total runoff.

[78] Benson, M. A., 1962, Factors influencing the occurrence of floods in a humid region of diverse terrain: U.S. Geol. Survey Water-Supply Paper 1580–B. (In press)

In the Cameron Run basin of northern Virginia, a flood inundation study by D. G. Anderson has led to the delineation of areas that will be inundated by floods having recurrence intervals of between 10 and 100 years. Effects of suburban development on flood flows have been evaluated, so that the areas delineated represent conditions expected to exist when the basin has been completely developed.

Ground water

C. F. Keech and J. B. Hyland have observed that the water table continues to rise in the loess-plain region west of Kearney, Nebr. This region has been irrigated with water diverted from the Platte River since 1938, and seepage losses have caused the water table to rise as much as 100 feet in some areas. In contrast to this condition, in the loess-plain region east of Kearney and south of the Platte River, where irrigation is almost wholly by ground water, the water table has persistently declined since heavy pumping began about 1955.

Recent studies in the Green Bay area, Wisconsin, by D. B. Knowles, have shown that the coefficients of transmissibility and storage of the sandstone aquifer, determined from a 3-year period of water-level recovery, agree very closely with those obtained from aquifer performance tests of a few days' duration.

F. C. Koopman, J. H. Irwin, and E. D. Jenkins (Art. 44) used a rubber inflatable straddle-packer assembly to isolate and test pump each of 5 sandstone and siltstone aquifers in an 8-inch diameter, 1,014-foot test hole near Las Animas, Colo.

I. J. Winograd (Art. 104) analyzed the potentiometric surfaces and the permeabilities of the rock units beneath three intermontane basins at the Nevada Test Site. The data suggest that the three basins are hydraulically connected through intensely jointed and faulted zones in the Paleozoic carbonate rocks that flank and underlie the basins. At Yucca Flat the data indicate that ground water moves downward through the Cenozoic aquifers into the more permeable Paleozoic carbonate rocks and then laterally out of the Valley.

The piezometric surface of brine in sandstone of the Delaware Mountain Group near Carlsbad, N. Mex., is anomalously low in places. However, according to E. R. Cox, reported water levels may not represent static conditions because the sandstone has low permeability.

Interrelations of surface water and ground water

Effluent streams in southwestern Suffolk County, Long Island, N.Y., flow on highly permeable Pleistocene outwash deposits; their low flows are well sustained by ground-water discharge. E. J. Pluhowski and I. H. Kantrowitz have found that about 70 percent of the outflow from the ground-water reservoir appears in the streams and is discharged directly to tidewater. The remaining discharge of ground water is in marshes near the shore or as submarine outflow.

The relatively high rate of stream-flow accretion along the middle reach of Champlin Creek in southwestern Suffolk County, Long Island, N.Y., is attributed to lateral rather than upward ground-water movement according to a study by E. J. Pluhowski and I. H. Kantrowitz (Art. 38). Upward movement of water is restricted to a thin zone whose boundaries are controlled by aquifer permeability and the difference in hydrostatic head between the aquifer and stream.

Water levels in a network of piezometers in the bed of Mullica River, Wharton Tract, N.J., were used by S. W. Lang and E. C. Rhodehamel (Art. 36) to determine areas of upward seepage of ground water to the river. Marked differences in head between the 1-foot and 2-foot level beneath the streambed indicate important areas of upward movement of ground water.

Ground-water levels, climatological data, and dry-weather stream flow of Pond Creek, Okla., have been correlated by W. E. Clark. The correlation charts may be used to forecast dry-weather flow of Pond Creek for several months. These correlations can also be used to compute the reduction in streamflow for any day due to evapotranspiration from the bottom lands, the rate of evapotranspiration of ground water from the bottom lands for any day, the approximate magnitude of change in bank storage for any day, and the average rate of recharge to the Rush Springs Sandstone. Also, a method is outlined for determining the effect on streamflow of any large withdrawals of ground water in the basin. The techniques and concepts can be applied to a variety of basins by changing the techniques to suit the individual basin.

In studies of movement of perched ground water in the alluvium in Mortandad Canyon near Los Alamos, N. Mex., J. H. Abrahams, Jr., E. H. Baltz, and W. D. Purtymun (Art. 37) found that snowmelt water filtering downward in sand beneath the stream accretes to the front of a ground-water mound, causing the front to advance faster than the ground-water body as a whole. Such complexities should not be overlooked in investigations of the rate of water movement, in the use of tracers, and in studies of chemical quality of ground water.

Ground-water temperatures along the flood plain of the Mohawk River in the vicinity of the adjacent well fields of the city of Schenectady and the town of Rotterdam, N.Y., have been used by J. D. Winslow (Art. 111) to demonstrate that the river recharges the sand and gravel aquifer underlying the flood plain, and to delineate the principal flow paths between the Mohawk River and the well fields. Variation of ground-water temperature with depth has revealed a wide difference in permeability between different beds within the aquifer.

The quantity of water available by induced infiltration of river water to a well field commonly is limited by layers of material of low permeability within the aquifer. S. E. Norris and A. M. Spieker (Art. 41) show that the lag and dampening of the annual water-temperature wave may be used as an indicator of the presence of beds of low permeability.

Analysis by M. J. Mundorff of ground-water levels, reservoir stage, and ground-water inflow to American Falls Reservoir, Idaho, indicates a direct relation between water levels and inflow to the reservoir, but gives little or no indication of seepage losses. That seepage losses are small is also suggested by geologic evidence obtained from many well logs, and measurements of spring discharge downstream from the reservoir.

According to E. R. Cox, lowering the water level in the alluvium under the flood plain of the Rio Grande south of Williamsburg, N. Mex., by spur drains or by straightening and deepening the channel of the river will not affect water levels and artesian heads of thermal water in the Magdalena Group of Pennsylvanian and Permian age and overlying alluvium in and near the town of Truth or Consequences. These two aquifers are separated by a ridge of relatively impermeable Precambrian rocks. Lowering the water level in the shallow aquifer near the river would lower the head in nonthermal artesian aquifers; but the lowering of head due to lowering water levels near the river probably would be small compared with the expected lowering of head in the artesian aquifers due to continued pumping of water from the artesian system.

An equation for estimating the changes in ground-water level resulting from impoundment of a stream is given by J. E. Reed and M. S. Bedinger (Art. 35). The equation applies to steady-state conditions in a semi-infinite aquifer.

Ground-water levels in the Kirwin, Kans., area, have risen as the result of construction of the Kirwin Reservoir in 1955. According to M. S. Bedinger and H. H. Tanaka, water levels in 1961 were as much as 40 feet above those of 1945-46. Water-level changes caused by impoundment of the river are attributed to the change in boundary component of head resulting from a rise in stage of the surface-water boundary of the aquifer, the change in accretion component of head resulting from a change in the geometric shape of the aquifer, and the change in accretion component resulting from an increase in transmissibility of the aquifer.

According to studies by Philip Cohen (1961a), gains and losses of streamflow of the Humboldt River in Northern Nevada coincide with changes of ground water in storage in the deposits underlying and bordering the flood plain of the river. Seasonal increase of ground water in storage and subsequent evapotranspiration are estimated to have accounted for about 10,000 acre-feet of the average annual decrease in streamflow in the Winnemucca section of the Humboldt River.

Low flows

Frequency curves of annual values of the lowest mean discharge of streams for periods of various lengths are easily prepared from data processed by a high-speed digital computer. C. H. Hardison and J. R. Crippen (Art. 45) use these frequency curves to estimate the number of days the flow of a stream remains less than a given discharge.

The frequency of low flows at various points on the Red River of the North, North Dakota and Minnesota, has been determined by H. M. Erskine. Frequency interpretations are made for the present schedule of regulation and for a projected schedule.

Time of travel of water

B. J. Frederick and P. H. Carrigan, Jr., found that under steady-flow conditions on the Clinch River near Oak Ridge, Tenn., the peak concentration of gold-198 radiotracer traveled about 10 percent faster than the mean velocity in the reach. R. G. Godfrey obtained similar results for steady-flow conditions on smaller streams and found that the center of gravity of the concentration traveled at the same speed as the mean velocity of the water in the stream. In the Clinch River study, the maximum level of radioactivity was reduced about 500 times in the first 3.7 miles of travel but was reduced less than 10-fold in the remaining 13 miles of the study reach.

EVAPORATION SUPPRESSION

Results of field tests made in Texas by G. E. Koberg and others using monomolecular films to suppress evaporation from small stock-water reservoirs were disappointing. Laboratory research produced dispersions of alkanols that were reasonably satisfactory insofar as dispersing and spreading were concerned. The use of a monomolecular film to suppress evaporation from stock ponds probably will not be economically feasible, because of the large amount of replenishment material needed to provide good film coverage.

ARTIFICIAL RECHARGE OF AQUIFERS

The Geological Survey investigated the feasibility of artificially recharging underground reservoirs in three different hydrogeological environments. These studies included recharge through wells and recharge through spreading basins and natural depressions called sinkholes.

Spreading basins

Studies by D. H. Boggess and D. R. Rima (1961) made at Newark, Del., show that little or no recharge to the principal aquifer would result from spreading water in shallow excavations owing to the presence of a zone of low permeability about 15 feet below the surface. The sands and gravels above the zone of low permeability, however, could be used for temporary storage of a large volume of storm runoff.

Sinkholes

Studies by W. S. Motts and R. L. Cushman made in the Roswell Basin of southeastern New Mexico show that sinkholes in the basin recharge area could be used for artificial recharge. The floors of some sinkholes are highly permeable and have the capacity to put more water underground than enters the sinkholes naturally. The floors of other sinkholes are relatively impermeable, but recharge wells drilled through the impermeable material would permit drainage into the aquifer.

Recharge wells

Data obtained by A. A. Garrett (Art. 107) from a recent series of recharge tests in a well in basalt at Walla Walla, Wash., show that well clogging by dissolved air may be minimized or eliminated if injection is restricted to short periods and the well is pumped between injection periods.

GEOLOGY AND HYDROLOGY APPLIED TO PROBLEMS IN THE FIELD OF PUBLIC HEALTH

The growth of population, urbanization, and industrialization, and the increasing use of radioactive materials have created problems involving public health and safety. The Geological Survey has been active in research concerning various aspects of some of these problems. Reported in this section are some recent findings in the fields of radioactive-waste disposal, distribution of elements as related to health, mine drainage, and pollution of water.

STUDIES RELATED TO DISPOSAL OF RADIOACTIVE WASTES

Studies related to disposal of radioactive wastes continued during the year on behalf of the Atomic Energy Commission. Included were investigations of mechanisms of ion-exchange and chemical transport and concentration, compilation of geologic information on sedimentary basins, gamma-ray logging, and physical properties of rocks and minerals.

Laboratory investigations

Dorothy Carroll made a preliminary study of the mineralogy, grain-size distribution, and ion-exchange capacity of sea-floor sediments in cores from near the Gulf of St. Lawrence, Newfoundland, and the coasts of Massachusetts and New Jersey. Samples from the cores were found to be mostly silty clays containing detrital mica and chlorite. Some samples contained sufficient mica for separation and X-ray examination. Cores supplied by the AEC from off the New Jersey coast were found to be mostly *Globigerina* oozes, but the lower part of a core collected about 250 miles from the coast in 2,000 fathoms of water was largely a red mud. More clay was found to exist 2 to 3 feet below the surface of the sea floor than at the surface, and the clay minerals were better crystallized. Chlorite in the samples was largely detrital, but there might also have been some that was authigenic. Small amounts of heavy minerals included blue-green amphibole, garnet, epidote and zoisite, and a little andalusite, sillimanite, and kyanite; opaque minerals were magnetite and pyrite. Zircon and rutile were very scarce and there was some tourmaline. Organic carbon was not abundant in the more southern cores. The ion-exchange capacity of these sediments ranged from 3 to 30 meq (milliequivalents) per 100 g with the highly micaceous samples averaging 10–11 meq per 100 g for the northern samples, and 3 to 11 meq per 100 g for the more southern samples.

In continuing studies of glauconite mineralogy, Dorothy Carroll examined by X-ray diffraction using Fe–K α radiation about 25 samples of glauconite ranging in age from Cambrian to Recent. The glauconites ranged from micas that have a crystallinity very similar to that of Fithian illite, to mixtures of mica and chlorite, and mica-chlorite-montmorillonite, and chlorite (chamosite?). A sample of clean pellet-form glauconite from Dunkirk, Md., was subjected to a pressure of 3,000 psi for 1 month by E. C. Robertson. This glauconite was unchanged in appearance, and X-ray patterns obtained before and after treatment were identical. Some glauconite, is, therefore, very stable under heavy pressure.

Dorothy Carroll also found evidence in experiments with Fithian illite that some of the previously reported results of titration of the H-form with NaOH are influenced by decomposition of the mineral. The supernatant solution contains appreciable amounts of K_2O and SiO_2, and smaller amounts of Al_2O_3. The titration curves for illite differ from those of vermiculite, suggesting mineralogical control of exchange mechanisms. In other experiments she found that reaction of sea water with vermiculite showed that the amounts of K that can replace Mg in interlayer positions is apparently limited by the relation between the charge deficiency of the vermiculite and the concentration of K to Mg and Ca in sea water. Vermiculite only partially reverts to biotite in sea water.

W. A. Schneider, H. Hughes, and E. C. Robertson found that each of two natural-salt samples tested showed a drop in thermal conductivity from 0.021 to 0.008 cal per cm sec deg C as a function of temperature from O°C to 300°C. The salt samples were from the floor of the Carey salt mine, Hutchinson, Kans., where tests are being conducted by the Atomic Energy Commission and Oak Ridge National Laboratories to determine the thermal behavior of radioactive wastes on the walls of chambers in salt beds. The salt is in the Wellington Formation of Permian Age. Values of the reciprocal of conductivity (the thermal resistivity) for the 2 samples fall on a straight line expressed by the equation $1/K=0.27T+43$, where K is thermal conductvity and T is temperature in °C. This relation is predicted by theory in statistical mechanics and shows that phonon conduction is the principal mechanism of heat flow for natural salt in the temperature range 0°C to 300°C.

Geologic and hydrologic field studies

Current thoughts on the storage of radioactive wastes underground and on management of radioactive wastes in a basalt terrane were reviewed by R. L. Nace (1961a, b). H. E. LeGrand (1962b) reviewed various geohydrologic factors in waste management and summarized the Geological Survey's function in this field (LeGrand, 1962d).

An imminent problem in waste management is the selection of sites for waste disposal; this consists of not only the designation of a site but also the establishment of criteria to be used in evaluating areas (Peckham and Belter, 1962). R. M. Richardson (1962) described two conditions which impair the suitability of sites in the northeastern United States for disposal operations: the effect of the humid climate and the lack of detailed information on the sorptive capacity of earth materials. H. E. LeGrand (1962d) stated that parts of northeastern North Carolina and southeastern Virginia appear favorable for confinement of wastes by deep-well disposal. He also recognized, however, that confinement is a relative term and that essentially complete confinement from the standpoint of conventional hydrology might involve unacceptable leakage from the waste standpoint.

In summarizing the geology of the Appalachian Basin, G. W. Colton concludes that structural features could be expected to be dominant factors in disposal of liquid radioactive wastes underground in this area. In the eastern parts of the basin, faults are common and well-developed axial-plane cleavage occurs in many areas in the older formations. Porosity is low in these formations as a result of metamorphic processes although, locally, highly porous areas may be found where joints and other fractures have developed.

Great thicknesses of Cambrian and Ordovician limestones and dolomites are found in the lower part of the basin. These are followed in ascending order by thick Ordovician clastic noncarbonate sediments which may offer much greater promise locally for waste disposal because they are more permeable in some areas where extensively fractured. In most areas these noncarbonate rocks are of no commercial value in the subsurface. Silurian and younger rocks contain coal or oil, gas, and other economic deposits that would require careful consideration if disposal of radioactive wastes in these formations should be proposed. Also, many of these formations have been extensively drilled in all but the deepest part of the basin. Three rock sequences may deserve more careful consideration: the early Silurian "Clinton" sands, evaporites of the Salina Group, and the sandstones, shales, and mudrocks of the Bloomsburg Redbeds.

Throughout most of their extent in the Appalachian Basin, the rocks of the Mississippian, Pennsylvanian, and Permian Systems generally are not believed suitable for waste disposal. Commonly they crop out or are close to the surface. Only in some areas, where the coal-bearing Pennsylvanian System is preserved, does the Mississippian System occur at depth. In most of the areas where this is the case, the Mississippian rocks have been densely drilled for oil and gas.

Statistical studies of relative dilution in the Clinch River near Oak Ridge, Tenn., were begun by P. H. Carrigan to determine ultimately the capacity of the river to dilute radioactive releases from Whiteoak Creek. The daily-dilution factor, the ratio of discharges of Clinch River near Scarboro, Tenn., to those of Whiteoak Creek at Whiteoak Dam near Oak Ridge, Tenn., for the period 1950–60 ranged from 5.1 to 4,330; the mean was about 450. The daily minimum-dilution factor for a recurrence interval of 10 years was 5.6; the monthly minimum was 68. The mean monthly dilution factor has been less than 450 for 5 months of a year.

The effect of variation of flow in Clinch River due to power releases from Norris Reservoir on the dispersion of radioactive releases from Whiteoak Creek near Oak Ridge, Tenn., also has been investigated by P. H. Carrigan. At a point 15.3 miles downstream from the point of release to the river the average concentration of radioactivity varied less than 10 percent in a 24-hour period while the discharge ranged from 1,700 to 7,700 cfs. For several days prior to the test the concentration and load of release from Whiteoak Creek had decreased very gradually and a series of similar power releases had been made.

Preliminary geologic studies of the Williston, Powder River, and Anadarko Basins have been made by C. A. Sandberg, Helen Beikman, and Marjorie MacLachlan, respectively, in evaluation of the possibilities of subsurface disposal of radioactive wastes. Sandberg concludes that in the Williston Basin (N. Dak., S. Dak., and Mont.), the Winnepeg Formation should be considered as a deep-horizon possibility, Permian and Jurassic salt beds as moderate-depth possibilities, and the Newcastle Sandstone as a moderate- to shallow-depth possibility. Beikman concludes that in the Powder River Basin (Wyo.), numerous sandstone beds, particularly the Newcastle Sandstone, should be considered as natural-reservoir possibilities. For storage of liquid wastes in artificially fractured shale or of fused or sintered waste in mined cavities, several Cretaceous shale beds, particularly the Mowry Shale, should be considered. MacLachlan concludes that sandstone beds of Late Pennsylvanian age, and salt beds common to five formations of late Early Permian age appear to be the most suitable zones in the Anadarko Basin (Okla., Tex., Kans., and Colo.). Units of Mississippian age and older lie at excessive depths in the trough, and detailed information on lithologic relations is not available.

Detailed field investigations of waste-disposal hydrology are in progress at the Idaho Chemical Processing Plant and the Materials Testing Reactor facilities, National Reactor Testing Station, Idaho, by P. H. Jones and Eugene Shuter (Art. 106). Modified oil-well testing techniques and geophysical tests in drill holes have been used effectively in the appraisal of the capacity of basalt aquifers and associated sediments to receive and attenuate radioactive waste (Jones, 1962a). The aquifers, accessible to waste, have been identified and correlated for distances greater than a mile. Their ability to transmit water and the hydraulic head and quality of water in the aquifers have been determined.

The relation between the physical properties of the volcanic Bandelier Tuff in the Los Alamos area, New Mexico, and the movement of water through the tuff with regard to the disposal of radioactive wastes have been studied by J. H. Abrahams, Jr. The porosity of the tuff is high, but the coefficient of permeability is relatively low because of the fine-grained texture. Cyclic layers containing sublayers of varying porosity exist throughout the upper member of the tuff and are traceable laterally across much of the Los Alamos area. These cyclic layers retard the vertical movement of water through the zone of aeration, which is about 1,000 feet thick. Secondary porosity developed along interconnected joints, however, allows rapid movement of water containing wastes through these nonporous zones in the tuff.

Geophysical investigations

A series of gamma-ray logs was obtained by C. M. Bunker in drill holes in and adjacent to a drainage field at Jackass Flats, Nevada Test Site, during the past 3 years. The logs were obtained at various time intervals during which a radioactive tracer and radioactive waste from a reactor rocket were released through tile into the field. Although the amount of radioactive material used was insufficient for a complete study of the distribution and rate of flow through the alluvium surrounding the tile, the data show that the fluid-borne radioisotopes were retained within a horizontal distance of 4 feet from the tile. The logs show no significant vertical movement of the radioisotopes. Vertical movement may be prevented by cemented zones which essentially parallel the original ground surface.

Equipment for making continuous measurements of radioactivity of lake and ocean sediments along predetermined traverses was field tested by Carl Bunker in Lake Superior. Although this was a preliminary investigation, the results indicate that measurements of this type are feasible. Similar measurements might be used to determine natural radioactivity of proposed waste-disposal areas and to monitor the areas after waste is deposited.

DISTRIBUTION OF ELEMENTS AS RELATED TO HEALTH

The Geological Survey is making available to the public, geological data that may be useful in the field of public health. In addition to maintaining liaison between health agencies and the Geological Survey, Sam Rosenblum is reducing radiometric data of the ARMS (aerial radiological measurement surveys) to contour maps.

Airborne radioactivity surveys were made in parts of Minnesota, Wisconsin, and Puerto Rico during the past year as the Geological Survey continued the ARMS program on behalf of the Atomic Energy Commission. This brings the total traverse miles flown between July 1958 and January 1962 up to 174,000, surveying about 186,000 square miles in 23 areas in the United States and Puerto Rico. The surveys were made in the vicinity of nuclear facilities primarily to establish a datum of background radioactivity for evaluating the effect on health in these areas. Further discussions of specific ARMS surveys may be found in the section "Regional Geology and Hydrology."

A study has been made by Helen Cannon of the absorption of vanadium by plants because vanadium has been shown to be important in human and animal nutrition. The absorption of vanadium by plants and the tolerance of plants to large amounts of vanadium in the soil were found to differ markedly in different species. The greatest tolerance was found in selenium-absorbing legumes, and the greatest concentration of vanadium occurred in the roots. The average content of vanadium in plant ash is about 20 ppm; herbaceous plants on the Colorado Plateau contained an average of about 170 ppm. Collections from areas containing vanadium deposits and from experimental garden plots showed that the vanadium content is abnormally low in plants rooted in calciferous rocks and abnormally high in those growing on seleniferous ground.

In support of public health studies, water samples from southern Wisconsin were analyzed for their minor-element content. Preliminary data supplied by H. T. Schacklette indicated that the iodine content of water from Precambrian and Paleozoic rocks of the Driftless Area of Wisconsin averages 0.009 ppm, and that water from the glacial drift averages 0.001 ppm. The strontium content of water from Ordovician and drift-covered areas is generally less than 0.02 ppm; water from Cambrian and Precambrian terranes ranges from 0.03 to 0.08 ppm.

ANTHRACITE MINE DRAINAGE

Hydrologic studies by W. T. Stuart and geologic studies by T. M. Kehn and J. F. Robertson show that improvements in surface drainage result in a reduction of the amount of water recharging the anthracite mines in Pennsylvania, thereby decreasing the pumping required and reducing the volume of acid and mineralized water being discharged into the surface streams. Fifteen projects completed under Public Law 162, 84th Congress, were designed to reduce inflow into the mines by restoring natural drainage. This was accomplished by backfilling strip-mine areas, and by lining stream channels to prevent seepage losses.

Owing to restoration of natural runoff, an estimated 400 million gallons of water annually per square mile, or 760 gpm, is being diverted from the mines of the Northern and Southern anthracite fields. Channel seepage loss of as high as 280 million gallons annually has been checked in one area by lining the stream channel.

CHEMICAL AND BIOLOGICAL ASPECTS OF WATER POLLUTION

In 1958 the development of the Greensburg oil field in Kentucky introduced a large amount of brine into the Green River. Chloride loads of the Green River at

Munfordville were computed based on daily chloride analyses and streamflow records. The double-mass curve technique of Searcy and Hardison[79] was far superior to the use of chloride concentrations in showing the degradation and improvement in brine pollution of the river. Brine pollution cf the Green River reached a maximum in the summer of 1959. Since then, water quality of the river has improved each year.

In a study of foaming characteristics of synthetic-detergent solutions, C. H. Wayman, J. B. Robertson, and H. G. Page (Art. 178) report that stable foams are formed with as little as 2 to 3 ppm of anionic and nonionic surfactants. Foam stability is enhanced by bacteria and low temperature and varies with pH.

The behavior of anionic alkylbenzenesulfonate (ABS), one of the chief components in commercial detergent formulations, toward soil minerals is of interest in pollution studies. Theoretically, ABS is adsorbed as a monomolecular layer at the surface of sand grains. From studies with sized fractions of 20–30 mesh Ottawa sand, C. H. Wayman (Art. 117) suggests that ABS adsorption on sand surfaces greater than 50 cm^2 per g probably takes place at less than a monolayer for dilute solutions containing as much as 100 mg ABS per liter. In such dilute solutions of ABS, experimental adsorption is equivalent to 50 percent of a monolayer of coverage.

As a part of a study being made on the behavior of detergents and other pollutants in soil-water environments, H. G. Page, C. H. Wayman, and J. B. Robertson have compared three commonly used methods of counting bacteria. They report (Art. 99) that the photometer method gives highly accurate and reproducible estimates within a few minutes as compared to about 48 hours by the gas-generation (MPN) and plate-count methods.

For studies of surface-active agents in natural water supplies, C. H. Wayman, J. B. Robertson, and H. G. Page (Art. 98) have designed a simple apparatus to measure foaming characteristics of aqueous solutions. The unit consists of a chromatographic column (5.8 cm outside diameter by 30 cm length and graduated to 0.5 cm) connected to a lower tube (1.0 cm outside diameter by 18.5 cm length) by a 55/35 tube-socket ground-glass point; a coarse-porosity fritted disc is sealed to the upper end of the lower tube.

The apparatus can be operated by releasing air or nitrogen at a constant flow rate into a solution containing a surface-active agent in the chromatographic column and observing the height of foam formation as a function of time. Foam stability can be determined by interrupting the gas flow through the system and observing the decrease in foam height as a function of time.

A study of the source of organic pollution in streams is discussed on page A93.

ANALYTICAL AND OTHER LABORATORY TECHNIQUES

Many factual data from the analytical laboratories of the Geological Survey have a direct bearing on a particular geologic or hydrologic project, so many findings from the laboratories have been reported earlier in this chapter under other headings. A very important part of the work in these laboratories, however, involves research in development and testing of new or modified analytical methods. Some of these methods are reported below together with some new developments in mineralogic and petrographic techniques.

ANALYTICAL CHEMISTRY

Methods of systematic silicate-rock analysis

L. C. Peck is preparing a manual that will present complete directions for the systematic analysis of silicate minerals and will include the description of special equipment developed and used in the laboratory.

Determination of rhenium

F. S. Grimaldi and F. O. Simon developed an improved method for the determination of rhenium based on the rhenium-catalyzed reaction between stannous chloride and sodium tellurate. The method is applicable to the determination of a few tenths of a part per million or more of rhenium in a few milligrams aliquot of mineralized rocks, mixtures of sulfides, rock-forming minerals, and molybdenite concentrates. The practical-quantity limit of detection is 2×10^{-10}g of rhenium. Rocks or molybdenite concentrates are decomposed with a flux consisting of a mixture of CaO, $CaCl_2$, and MgO. The MgO acts as a combustion aid, the $CaCl_2$ decomposes silicates, and the CaO converts molybdenum to insoluble $CaMoO_4$. On leaching the melt, all the constituents of the sample are rendered insoluble except for a small amount of molybdenum and calcium that pass into the filtrate. Residual molybdenum is removed by extraction with 8-quinolinol in chloroform. A decontamination factor of molybdenum from rhenium of at least 10^7 is obtained. The determination is completed spectrophotometrically by measuring the absorbance of the tellurium sol formed by the reduction of tellurate by stannous chloride under the catalytic influence of rhenium.

Minor elements in the Pierre Shale

A study of the analytical precision of chemical methods for determining selected minor elements in the Pierre Shale was reported by L. F. Rader and F. S.

[79] Searcy, J. K., and Hardison, C. H., 1960, Doubles-mass curves: U.S. Geol. Survey Water-Supply Paper 1541–B, p. 31–65.

Grimaldi (1961). Detailed procedures for determining titanium, vanadium, chromium, manganese, cobalt, nickel, copper, zinc, lead, arsenic, selenium, molybdenum, tungsten, uranium, carbonate carbon, total carbon, and organic matter are described. The precision of the analytical methods was established from replicate determinations made on different days by one chemist, replicate determinations by one chemist on paired hidden splits, and crosscheck determinations on 10 selected samples by different chemists, laboratories, and methods. Graphic comparisons were made of determinations by different chemists to indicate either the agreement or the bias of results.

The beryllium-morin system

Mary Fletcher has found three beryllium-morin complexes in aqueous solution. The beryllium-morin ratio was determined for each of the three complexes; equilibrium constants were calculated for two of them and a tentative value for the third. The absorption spectra for morin and its beryllium complexes are so nearly alike that fluorimetric measurements had to be relied on entirely for the resolution of the system.

Fluorescence studies

A theoretical study was completed by Mary Fletcher which evaluates fluorimetry with a vertical-axis transmission fluorimeter and compares it with spectrophotometry for the study of multicomponent mixtures. This study shows how for some systems the general equation for fluorescence previously derived by Milkey and Fletcher [80] can be transformed into a much simpler expression analogous to and amendable to the same manipulations as its counterpart for the total absorbance of multicomponent mixtures. With this equation one can readily select experimental conditions for a fluorimetric analytical method giving maximum sensitivity and reliability with minimum complications from diverse ions.

Determination of boron in waters containing fluorine

J. J. Rowe (Art. 48) showed that fluorine is volatilized during the sulfuric acid evaporation step and does not interfere in the dianthrimide spectrophotometric procedure for determining boron. Sulfuric acid solutions of the samples are evaporated overnight in an oven at 90°C. Tests made with up to 1 mg of fluorine showed no interference with as little as 0.004 mg boron.

Flame photometric determination of calcium in thermal waters

The radiation interferences of silica and sulfate on the flame-photometric determination of calcium in thermal waters was investigated by J. J. Rowe. A flame-photometric method, without any chemical separations, was developed. An addition technique was coupled with the use of magnesium as a releasing agent to overcome the depression of calcium emission caused by silica and sulfate.

[80] Milkey, R. G., and Fletcher, M. H., 1957, Fluorimetric study of the fluorine-morin system: Am. Chem. Soc. Jour., v. 79, p. 5425–5435.

Determination of lead in sphalerite

C. A. Kinser adapted the dithizone method to the determination of trace amounts of lead in sphalerite. His procedure is capable of detecting as little as 5 ppm lead in 25- to 50-mg samples. Further extension of the sensitivity is being studied, as is the application of the procedure to the determination of lead in various silicate minerals.

Apparatus for ferrous iron determination

An instrument to aid in the routine determination of ferrous iron was designed and built by L. Shapiro and F. Rosenbaum (Art. 100). It consists of a motor-driven wheel which rotates slowly over an electric strip-heater. Twenty samples, in platinum crucibles containing $HF–H_2SO_4$, are seated in holes along the periphery of the wheel and move slowly over the heater. A sample is available to be titrated every 3 minutes, after having been boiled for 10 to 12 minutes.

Alkali metals in micas

D. N. Rimal, International Cooperation Administration doctoral student from Nepal, working with the assistance of J. Dinnin, determined flame photometrically the lithium, rubidium, cesium, potassium, and sodium content of 50 micas from New Mexico.

Silica in tektites and glasses

A method for determining the silica content of tektites and similar glasses by the direct volatilization of silica as SiF_4 with HF was developed by M. K. Carron and Frank Cuttitta (Art. 30). The resulting fluorides in the residue are converted to nitrates which in turn are decomposed with formaldehyde. The residue is ignited to constant weight at 750°C±15°C. A correction for the FeO content of the glass must be applied to the silica result.

Selective solution of fluorite

R. E. Stevens and others (Art. 96) found that fluorite can be removed from powdered samples by boiling in a 50 percent w/v solution of $AlCl_3 \cdot 6H_2O$. The formation of an aluminum complex with fluoride results in the solution of fluorite without attack on silicate minerals. The procedure is being used on samples from Alaska that contain phenacite, beryl, chrysoberyl, and tourmaline to obtain better X-ray patterns for identifying and confirming the beryllium minerals.

Standard samples

J. I. Dinnin found that by measuring the titanium peroxide color at pH 2.0, rather than in 10 to 20 percent acid, the vanadium interference in this determination can be greatly reduced. This method, as well as a Tiron-EDTA procedure, was used to determine 0.01 to 0.05 percent Ti in five samples of ferrochrome which are to be used as fluorescent X-ray standards in connection with commercial-specification analysis of domestic ferrochrome. The values checked well with results obtained spectrographically by H. Bastron. The chemical methods were also used to obtain a value of 0.014 percent Ti in the National Bureau of Standards Standard Ferrochrome 64b for which no previous Ti value was available.

Extracting water from cores for chloride analysis

During an investigation of salt-water encroachment in southern Nassau County, Long Island, N.Y., a filter press was used to obtain water from drill-core sections (Lusczynski, 1961a). It was found suitable not only for extracting water from sand and silt, but also from clay. The interstitial water was extracted from the core, and the filtrate was subsequently analyzed for chloride by titration in the field within minutes after the core was brought to the land surface.

SPECTROSCOPY

Spectrochemical analysis of small samples

A method of spectroscopic analysis of very small samples (1 mg or less) that has been extremely useful for mineralogical and chemical studies has been reported by C. L. Waring and Helen Worthing (1961). Visual estimates of othe concentrations of 68 elements are made from comparisons of the photographic records of the spectra of the samples with reference spectra made with known standards. A simple device built into the plate holder of the spectrograph permitted limiting the exposure of the long wavelength region to the early part of the arcing period, during the time the alkali elements are in the vapor. Overexposure of that region thus is avoided and the simultaneous determination of all elements implemented.

Semiquantitative spectrochemical analysis of rocks, minerals, and ores

A report by A. T. Myers and others [81] brought up to 1961 details of the procedure for the semiquantitative spectrographic determination of minor elements in geologic materials. The method provides for the simultaneous determination of 68 elements by a visual-comparison procedure in which concentrations were estimated to ⅓ of an order of magnitude, that is, 0.7 percent, 0.3, 0.10, 0.07, etc. The speed of the analysis and the method of reporting results made this procedure of great value in reconnaissance studies. A 10-mg powdered sample buffered with graphite and sometimes silica is burned in a d-c arc. Concentrations were estimated from comparisons with reference spectra. Experience in applying this method to many samples indicated the feasibility of extending the reporting precision to six steps per order of magnitude; that is, 0.7 percent, 0.5, 0.3, 0.2, 0.15, 0.10, 0.07, 0.05, etc. To prevent this change from making the procedure excessively complex, especially the problem of standards, the number of elements routinely reported was reduced to 51. Three additional elements are reported if requested, and 15 others if certain "indicator" elements are found to be present.

The need for expanded analytical services of the type described above raises the question of the applicability of direct-reading instrumentation for recording spectra. There would be a large saving in time and labor for such analyses if the photographic part of the procedure were eliminated. Considerations of the spectral lines to be used and the degree of spectral complexity that can be handled by direct-reading instruments currently manufactured has indicated this approach to be feasible. An instrument to determine 22 elements with a single exposure is being installed in the Denver laboratory. The instrument capabilities later may be expanded to determine an additional 22 elements. Fourteen standards containing 26 elements to be used for direct-reading work have been prepared.

Quantitative spectrographic analysis for selected minor elements in Pierre Shale

The availability of a large number of similar samples on which much analytical work, chemical as well as spectroscopic, will have been done, gave P. R. Barnett (1961) an excellent opportunity to make a detailed study of the precision of the conventional d-c arc procedure for 10 minor elements as applied to shales. He determined from 80 samples the following values for the precision of a single determination (in terms of the coefficient of variation of a single determination): boron, 10 percent; barium, 11; cobalt, 7; chromium, 9; gallium, 20; nickel, 7; scandium, 10; strontium, 13; titanium, 6; and zirconium, 10 percent. Eight of these elements in 10 samples were also determined by a second spectographic laboratory. The precision between laboratories was as follows: boron, 10 percent; barium, 12; cobalt, 16; chromium, 11; gallium, 16; scandium, 12; strontium, 10; and titanium, 10. Comparisons were also available with values obtained by chemical methods yielding the following coefficients of variation between determinations by chemical and by spectographic methods: barium, 34 percent; cobalt, 12; chromium, 10; nickel, 7; and titanium, 10 percent.

[81] Myers, A. T., Havens, R. G., and Dunton, P. J., 1961, A spectrochemical method for the semiquantitative analysis of rocks, minerals, and ores: U.S. Geol. Survey Bull. 1084–I, p. 207–229.

Direct-reading spectrochemical-methods development

In a continuing program at the Washington, D.C., laboratory, A. W. Helz and others have been studying excitation conditions favorable for high precision as well as capable of extension to lower concentrations. The lithium tetraborate fusion pellet method was found to give poor precision with chromite ores. It may be significant that after fusion these materials produced a devitrified product rather than a clear glass. Very even burning was obtained in the d-c arc with electrode charges consisting of 1 part sample, 0.5 parts MnO_2, and 6 parts C. This work was conducted with direct-reading observations of Fe, Cr, Si, Al, and Mn lines. In order to diminish self-reversal of the spectral lines, tests were made with the stallwood jet and a jet designed to use both air and argon-oxygen mixtures. High d-c arc precision relative to a time of burning schedule was obtained but not relative to a manganese internal-standard schedule.

In another direct-reading study, detectability tests were made with volcanic-glass standards for Ta, Mo, W, Be, V, Cu, and Zn. The conventional d-c arc was used. The following exit slits were set up: Ta, 2714.67 A; Mo, 2816.15 A; W, 2946.98 A; Be, 3131.07 A; V, 3185.40 A; Cu, 3247.54 A; and Zn, 3345.02 A. These were not the most favorable lines for Ta, Mo, and W, but they were used because of compromises necessitated by space limitations at the focal curve of the particular instrument used. Excellent analytical curves were obtained which indicated that the procedure without modification would yield the following detectabilities, in percent (the numbers in parentheses are detectabilities for the conventional photographic procedure): Ta, 0.01 (0.02); Mo, 0.002 (0.0002); W, 0.003 (0.02); Be, 0.0004 (0.0001); V, 0.0002 (0.0005); Cu, 0.0001 (0.0001); and Zn, 0.005 (0.03).

X-ray fluorescence analysis

A procedure for the determination of all the major elements of atomic numbers above 11 in silicate and carbonate rocks has been established by H. J. Rose, Jr., Isadore Adler, and F. J. Flanagan (Art. 31). The method of sample preparation is a $Li_2B_4O_7$ fusion technique with the addition of La_2O_3 to minimize variable-absorption effects. Notable features of the procedure are the speed of analysis and accuracy of the results. An application to the analysis of tektites for Si, Al, Fe, Ca, K, Mn, and Ti and comparison of results with those of chemical methods indicates coefficients of variation for each element, expressed as percent standard deviation of a single determination of about 2 percent. The variation for SiO_2 determinations (Art. 30) is less than 1 percent. In a special application to the determination to thallium in manganese ores (Rose and Flanagan, Art. 32) 100 mg of the powdered sample is mixed and pelletized with 900 mg of H_3BO_3; the fusion was unnecessary to obtain results in excellent agreement with chemical values. Standards were prepared for this application with a matrix similar to that of the material analyzed.

The X-ray fluorescence method is well suited for rapid and automated analysis. For this purpose a new instrument has been obtained to record nine elements simultaneously. The first application of this X-ray spectrometer was the analysis of a sample of siderophyllite from Minas Gerais, Brazil. The results compared with those of chemical values previously obtained are given below, in percent.

	X-ray fluorescence	*Chemical*
SiO_2	33.4	33.38
Al_2O_3	17.6	18.18
Fe_2O_3	35.2	35.15
K_2O	7.60	7.60
TiO_2	1.72	1.71

MnO, CaO and MgO below 0.1

The time required for such an analysis, including grinding the sample, fusion, homogenization, pelletizing, and instrumental run is 45 minutes.

Electron-probe X-ray microanalyzer

The mineral mackinawite found in the Mackinaw mine, Washington, in the form of microscopic grains of about 5×15 microns cross section, has been analyzed by means of the electron probe by Cynthia Wooster and Isidore Adler. The question of its relation to valleriite, a mineral from Kavelthrope, Sweden, has been under study for some time. It was possible to demonstrate that these minerals are not related and that mackinawite is a new iron-nickel sulfide mineral containing 63 percent iron, 34 percent sulfur, and 3 percent nickel. The formula $(Fe, Ni)_9S_8$ was suggested, which compares with the synthetic mineral kansite, Fe_9S_8. This is in accord with X-ray diffraction data.

Other noteworthy applications of the electron probe by Isidore Adler and E. J. Dwornik are: (1) A large number of crystals of iron-nickel phosphide (schreibersite) in the Canyon Diablo meteorite were analyzed for iron and nickel; it was shown that these grains were variable in composition. (2) The successful application to several natural platinum-alloy samples demonstrated the value of this technique as a nondestructive method for study of natural platinum alloys, mixed phases, and included minerals. (3) White inclusions of 1 micron diameter and less in a fragment of Martha's Vineyard tektite were shown by a traversing technique to contain about 17 percent zirconium. (4) The presence of iron and phosphorous and the absence of nickel in 1- to 5-micron-diameter inclusions in spherules in

Philippine tektites was proved. (5) Heated and unheated bornite were studied to determine compositional variation in and surrounding blebs of chalcopyrite; the copper, iron, and sulfur concentrations were found to be constant.

Identification of thalenite by means of absorption-band spectra

The rare yttrium silicate, thalenite, has been identified by J. W. Adams and others (Art. 121) as a constituent of a rare-earth mineral assemblage in a pegmatite in Teller County, Colo. Thalenite closely resembles quartz in appearance and its occurrence in other deposits could be overlooked. Recognition of the mineral is facilitated by the absorption bands of erbium, which are apparent when thalenite is examined with a band spectroscope or microspectroscope.

MINERALOGIC AND PETROGRAPHIC TECHNIQUES

Phillip Bethke and Paul Barton have developed a scheme for preparing polished slabs of transparent ore minerals such as sphalerite on a fairly routine basis. These sections, viewed in transmitted and reflected light, provide a wealth of paragenetic details unobtainable in reflected light alone.

R. A. Cadigan has developed an empirical system of classification of the relations between particle size (mean grain size) and tectonic uplift or energy level, and between sorting (standard deviation of grain-size distributions) and rate of subsidence or accumulation. Each sample can be classified in terms of the local rate of application of energy (energy level) and local rate of accumulation in the area of transportation and deposition. The tectonic environment classification which is now in the test stage, is based on a "V-shaped" grid superimposed over a phi mean grain size (x)—phi standard deviation (y) grid. Intensity of energy application or energy level is measured from parallels to the right arm of the "V"; the formula for these parallels is $x=1.666y+C$. Rate of accumulation is measured from parallels to the left arm of the "V"; the formula for these parallels is

$$x=\pm 1.666y+C^{-n \cdots +n}.$$

where x is the phi grain size, y is the phi standard deviation, C is the constant integer of the phi grain size, and n 10.

Measure of intensity of energy increases as the values of C go from positive to negative. Measure of rate of accumulation increases as values of C go from negative to positive values. The two measures are redefined on a regional scale as intensity of tectonic subsidence in the area of sediment deposition (accumulation). An algebraic numeral or a symbol on each parallel of the "V" grid makes it possibe to assign an energy-environment index and a rate-of-deposition index to each sample. Interpretations are thus more objective and can be made more rapidly.

F. C. Calkins (Art. 102) has developed two instruments—an open loop and a "contact" pipet—for handling relatively uniform small amounts of liquids for use in refractive-index work or in microchemical tests.

T. F. Beckers and B. C. Colby have shown that a commercial instrument can be used to determine accurately the concentration and size distribution of suspended sediment in the size range 1 to 200 microns. The instrument operates on the change of electric resistance in a small aperature as particles in a dilute suspension in a conductive liquid pass through. In general, the analyses take longer than those made by pipet or bottom-withdrawal tube methods.

D. B. Stewart (Art. 29) has studied the fusion method for determining the SiO_2 content of Hawaiian rocks and for possible use in distinguishing the differentiates of the tholeiitic and alkali basalt magmas. About a gram of the representative rock, ground to pass a 200-mesh sieve, was fused for 90 seconds in a 5-ampre 220-volt d-c arc. The index of refraction was measured to ± 0.002 on the crushed beads using white light and freshly calibrated immersion oils and white light. Determinations made on 19 analyzed Hawaiian rocks indicate low accuracy for the determination of SiO_2 content. The tholeiitic glasses tend to have a higher index of refraction than glasses fused from alkali basalts, but overlapping of ranges of the two series precludes the assignment of an unknown rock to either.

The mutual solubility of the mineral pair, paragonite-muscovite in the two coexistent phases depends on the metamorphic grade, and the solubility is sensitivity reflected in the basal (001) spacings, which can be accurately measured. E-an Zen has measured and compiled such pairs of spacings on coexistent muscovite and paragonite from samples collected in New England and elsewhere in the United States and in Europe. A good least-square straight line can be fitted to all the data; the slope of the line is very far from unity and suggests considerable asymmetry to the solvus. A major complicating factor is the component $CaAl_2Al_2Si_2O_{10}(OH)_2$ (end member phase is margarite); the possible influence of this component can only be guessed at now, but may account for the scatter of the observed data. More chemical data are needed to settle this point and may be available from an unusually good paragonite sample (less than 2 percent of other phases) which has been separated for chemical analysis.

DEVELOPMENT OF EXPLORATION AND RECORDING TECHNIQUES

The development of new exploration and recording techniques and new applications of known techniques receive the attention of many members of the Geological Survey. Working together on many such studies are scientists of various disciplines including chemistry, physics, botany, and mathematics in addition to geology and hydrology. Equipment design and application are an integral part of efforts to improve methods of measuring and recording geologic and hydrologic data.

GEOCHEMICAL AND BOTANICAL EXPLORATION

Present information suggests that zinc-rich magnetites are derived from igneous rocks that are genetically related to ore deposits. Studies by P. K. Theobald, Jr., and C. E. Thompson (Art. 84) have shown that (1) the zinc content of magnetite generally falls into 1 of 3 ranges: background below 100 ppm, (parts per million), (2) threshold range from 100 to 300 ppm, and (3) potential association with zinc ore above 300 ppm. If continued work supports this apparent relation, it could provide a powerful new tool for geochemical prospecting.

Geochemical work at the Getchell mine, Nevada, by R. L. Erickson and others has demonstrated that arsenic, mercury, and tungsten anomalies occur in residual soil, caliche, and fracture coatings in barren bedrock over concealed gold ore. The anomalies are not broad halos but are restricted to the mineralized area. Preliminary paragenesis observations suggest that gold deposition is intermediate in time between earlier arsenic tungsten and later mercury, and overlaps both. Thus, a coincidence of high arsenic, mercury, and tungsten anomalies is a more favorable indicator of concealed gold ore than single anomalies of these metals.

L. E. Patten and F. N. Ward (Art. 101) report that the reaction between beryllium and morin to form a fluorescent compound is practically specific and is the basis for a field method for determining as little as 1 ppm beryllium in soils and rocks. After the sample is fused with ammonium bifluoride, followed by leaching with nitric acid and complexing of interfering ions, the fluorescence is measured by visual comparison with standards.

Using this new beryllium procedure, W. R. Griffitts and John Cieslewicz found that the beryllium content of alluvium in limestone terranes seldom exceeds 5 ppm, even within one-quarter mile of beryllium deposits. Soils near the deposits, however, may contain 50 ppm or more.

Field studies by H. T. Shacklette in the mineralized part of the Driftless Area of Wisconsin have shown consistently greater amounts of zinc in the A horizon of undisturbed soils not over known ore deposits than were found in the B or C horizons. This concentration in the A horizon is apparently the result of the growth and decomposition of vegetation and is evident both in soils that develop on loess and in soils that develop directly on weathered bedrock. Thus, in the Driftless Area the zinc content of the A soil horizon should be more useful in reconnaissance geochemical prospecting than the zinc content of the other soil horizons.

Appraisal by F. C. Canney of geochemical data obtained from the resampling by L. Pavlides of several molybdenum stream-sediment anomalies in the Smyrna Mills quadrangle, Aroostook County, Maine, suggests a possible correlation between anomaly intensity and climatic variations, with the anomaly contrast diminishing during periods of high rainfall and runoff.

The geochemical-prospecting field procedure for zinc has been revised as the result of a limited restudy of the method by F. C. Canney and G. A. Nowlan. The revised procedure is believed to give more reliable data in the lower concentration ranges, and especially with samples containing higher-than-average amounts of aluminum.

Additional chemical studies by L. C. Huff in the Pima mining district of Arizona have revealed that mesquite, a deep-rooted tree, accumulates zinc, lead, silver, barium, and strontium, in addition to copper and molybdenum. The analysis of mesquite leaves and twigs, therefore, may be useful in the search for ore hidden beneath alluvium in the Basin and Range province.

L. S. Hilpert finds, from 85 samples taken in and near uranium ore in the Todilto Limestone of northwestern New Mexico, that the average content of vanadium in the ore is about 0.15 percent and shows a progressive decrease outward through weakly mineralized ground and through 3 barren zones to about 0.002 percent in the outermost zone, about 1 mile from mineralized ground. Phosphate averages about 0.01 percent in the ore, 0.04 percent in weakly mineralized ground, and then shows a progressive decrease outward through the barren zones to about 0.03 percent in the outermost zone. By contrast, the average contents of sulfur and organic carbon are about 0.04 and 0.1 percent, respectively, in the ore, and show an increase to about 0.3 and 0.7 percent, respectively, in the outermost zone. No data are available on organic carbon for weakly mineralized ground and the inner barren zone. All four of these substances may be useful as regional guides to hidden ore deposits in the Todilto. Vanadium is particularly useful because of the more distinctive differences in content between sample zones; however, the four should be used collectively to be most effective.

APPLICATION OF ISOTOPE GEOLOGY TO EXPLORATION

Investigations being made on the isotopic composition of carbon, hydrogen, lead, and oxygen have shown large differences that are shedding new light on the origin of mineral deposits. The application of isotope geology to geochronology is discussed on pages A93 to A94.

Isotope geology of hydrogen

The variation in isotopic composition of hydrogen in primary fluid inclusions in ore and gangue minerals from Mississippi Valley-type deposits is being investigated by Irving Friedman and W. E. Hall. They have found that fluid inclusions in minerals in the Upper Mississippi Valley lead-zinc deposits have a variation similar to that in the southern Illinois fluorite district (U.S. Geol.. Survey Prof. Paper 400–A, p. A69). Water extracted from early ore minerals is heavy and has a relative deuterium concentration typical of connate water. Fluid inclusions in later minerals are successively depleted in deuterium.

Isotope geology of oxygen

R. N. Clayton and S. Epstein [82] have shown that if there is isotopic equilibrium between coexisting mineral pairs, the relation of the isotopic fractionation of oxygen between the minerals is a function of temperature. The application of this principle to the study of alteration halos in carbonate rocks around mineral deposits is apparent.

T. S. Lovering, J. H. McCarthy, Jr., and H. W. Lakin are working on the falling-drop method of density determination to determine the relative differences in oxygen isotope ratios in carbonate rocks. Carbon dioxide is released from the rocks and reacts with hydrogen gas to produce water and methane. The density of the water, which is a function of the O^{18}/O^{16} ratio in the rock, is then measured by the rate that it falls through an immiscible liquid of nearly the same density. During the year, different methods of decomposing the rock have been investigated. Rapid thermal decomposition of the carbonates to evolve carbon dioxide is currently under investigation. The method is designed to provide a rapid and inexpensive means of obtaining oxygen isotopic data for geochemical exploration.

W. E. Hall, Irving Friedman, and A. V. Heyl are investigating the variation in isotopic composition of carbonate host rocks around Mississippi Valley-type ore deposits. They find very little difference in isotopic composition of coexisting calcite and dolomite in alteration zones about ore bodies in the Upper Mississippi Valley lead-zinc district. Both minerals are slightly depleted in O^{18} nearer ore bodies.

HYDROLOGIC MEASUREMENTS

Well logging

Thousands of water wells in the Atlantic and Gulf Coastal Plains have been logged by subsurface geophysical methods, mainly electrical and gamma ray. A. N. Turcan (Art. 116) finds that the relation of the salinity of water in selected aquifers of Tertiary age in Louisiana to the resistivity reading on electrical logs of wells in a given area can be established empirically, using chemical analyses of water from a large number of wells for which electric logs are available.

G. E. Siple has observed that beds of sand in the Tuscaloosa Formation of Cretaceous age and overlapping sediments of Tertiary age in South Carolina show both high resistivity on the electrical logs and high intensity on the gamma-ray logs. This is in contrast to the usual low intensity of gamma radiation logged for beds of sand, and is believed to indicate the abundance of radioactive mineral grains in the sands. Gamma-ray logs show this feature for wells over the entire belt, from the Savannah River on the south to the Pee Dee River on the north.

Geochemical studies of ground-water facies in basalt aquifers at the National Reactor Testing Station, Idaho, based on temperature and water-resistivity logs and complete chemical analyses of water from many of the wells, have provided new information on the source, direction of flow, and the geochemical effect of the rock environment on ground water. F. H. Olmsted has converted temperature and electrical-resistivity logs of water wells to specific-conductance logs, and has obtained accurate values for the sum of ionized constituents in the water, which ranges from about 200 to 540 ppm in the 90 square-mile area studied. Waters that can be readily identified on the specific-conductance logs of wells are (1) return flows from adjacent irrigated lands, (2) waste water from nuclear test facilities and a chemical processing plant, (3) underflow from nearby valleys draining mountain areas to the north, and (4) mineralized water that may be derived from subsurface thermal springs. The effect of seasonal changes in the distribution and character of these geochemical facies is observed by logging the wells every 3 months.

[82] Clayton, R. N., and Epstein, S., 1958, The relationship between O^{18}/O^{16} ratios in coexisting quartz, carbonate, and iron oxides from various geologic deposits: Jour. Geology, v. 66, p. 352–373.

Instrument design and application

The acoustic velocity meter [83] using ultrasonic waves for continuous recording of the mean integrated velocity on a horizontal line within a stream is now being investigated on the basis of a cycled-pulse technique. The difference in transit time of upstream and downstream pulses (function of water velocity) can be recorded at discrete intervals on punched tape for final analysis by computer.

G. F. Smoot, using miniature strain gages developed by Battelle Memorial Institute, has designed equipment to measure turbulence-induced pressure fluctuations in flowing water. The sensing probe consists of a 0.5-inch-diameter sphere with 0.001-inch×0.25-inch diaphragms mounted on each of the 3 axes. Strain gages attached to the inside of each diaphragm thus respond to the three components of turbulence.

The magnetic-switch contact chamber, designed by G. F. Smoot and S. E. Rickly, replaces the regular contact chamber of the standard Price current meter and allows the use of a small battery-operated counter. A small magnet, mounted on the vertical shaft of the meter, is rotated beneath a sealed "Glaswitch," causing two contact closures per revolution of the meter rotor.

E. G. Barron and G. F. Smoot have improved the design of a vertical-vane-type meter (previously worked on by A. H. Frazier and others) to produce a satisfactory meter for use in measuring the velocity of water flowing under ice cover. The four vertical vanes of the rotor are less affected by vertical movement of the meter or vertical components in the flow, and the smaller size allows the meter to be inserted through a 5-inch hole drilled in the ice. The meter is also equipped with the magnetic-switch contact chamber described above.

Equipment for the measurement of water level in small-diameter wells was designed and evaluated by Eugene Shuter and A. I. Johnson (1961). Two models were determined to be satisfactory for additional field testing prior to advocating widespread field use.

H. H. Stevens, Jr., and B. C. Colby have developed and tested an intermittent pumping sampler that automatically pumps samples from a stream at preset time intervals. Although the primary objective was the determination of suspended-sediment concentration in a stream, the samples could be retained for other purposes. In addition to the retention of individual samples for subsequent analysis, a camera was used to photograph periodically the volume of sediment that settled out of a pumped sample in a given period, or the accumulated weight of sediment was recorded.

[83] Wires, H. O., 1961, Development of an ultrasonic method for measuring stream velocities: Art. 27, *in* U.S. Geol. Survey Prof. Paper 424–B, p. B58–B60.

RESEARCH AND DEVELOPMENT IN TOPOGRAPHIC SURVEYS AND MAPPING

All major phases in the preparation of topographic quadrangle maps benefited by research and development during 1962. To provide guidance for this research effort and to evaluate procedures, standards, and instruments, the Geological Survey carries on an accuracy-testing program. In this program a representative 10 percent of the quadrangles is tested by special surveys for both position and elevation accuracy. The tests are designed to give results that can be subjected to statistical analysis. The evaluated test findings are an important aid in selecting optimum methods for new mapping, in designing research in operations, and in formulating standard procedures.

Long-range research has been devoted to improving the basic information content of topographic maps by the addition of photoimagery and to producing map supplements or map substitutes based on orthophotography in various forms.

The highlights of research accomplishments in topographic surveys and mapping are summarized below.

FIELD SURVEYS

Portable surveying tower

Lightweight, portable towers for control surveys have been designed by J. L. Buckmaster and others. The tubular aluminum towers are triangular in cross section and can be built from 14 to 74 feet high in 6-foot increments. Each foot of height of the tower weighs approximately 5 pounds. A unit consists of an outer tower to support the observer, and an independent inner tower to support the instrument. The towers can be transported assembled as a trailer, by truck, or by helicopter.

The tower itself serves as the trailer when it is transported trailer-fashion, and the wheels attached to the outer tower remain in place when the tower is erected. A 2-man team can erect an assembled 50-foot tower in approximately 2 hours by means of a small hand winch and a boom. For long moves it can be completely disassembled and transported by pickup truck. The tower meets the requirements of a wide range of surveying operations using theodolites, signal lights, and electronic distance-measuring instruments.

In recent experiments assembled 36- and 50-foot towers have been mounted on pickup trucks. These truck-mounted towers, with outriggers and a winch, can be erected by one man in less than 15 minutes, saving considerable field time in selecting station sites.

Airborne control system

Preliminary field tests have been completed successfully by J. L. Buckmaster and others on a new system of establishing horizontal and vertical mapping control in which positions are established by coordinated angle and distance determinations from several known control stations to a helicopter hovering above the desired station.

In operation, the helicopter serves both as an aerial platform over the station for which a position will be determined and an elevated target for measuring horizontal and vertical angles. The helicopter is equipped with a high-intensity rotating beacon, to serve as an aiming point; a height indicator, to enable the pilot to maintain a specified height above the ground; and a hoversight, an optical viewing device, to enable the pilot to position the helicopter directly over the station. Distances to the helicopter from two or more ground stations of known position are determined by an electronic distance measuring instrument, and vertical and horizontal angles are measured by theodolites.

Distances have been determined accurate to 1 part in 20,000 with reasonable consistency for hover heights up to 200 feet, but the accuracy of elevation determinations has not yet been established.

Target design for photoidentification of control

Data to improve the design of targets used for photoidentification of ground control were obtained from tests carried out in 1960 and 1961 by David Landen (Art. 58) and others. Targets of various sizes, patterns, and materials were laid out in a test area, then photographed at various flight heights with a standard mapping camera. In addition, supplemental black-and-white and color photographs were obtained with a short-focal-length 35-millimeter camera. The target photographs were evaluated by observation in a stereomodel to determine the best configurations, minimum sizes, and most suitable materials.

Elevation meter

Two new elevation meters for determining supplemental control elevations for topographic mapping were acquired in 1961. The meters, which were built by the Sperry-Sun Well Surveying Co., based on specifications developed jointly with J. L. Speert (Art. 59) and others, are transistorized, electromechanical vehicle-borne devices for measuring differences of elevation along a traversed route. Instantaneous slope is measured continuously by a sensitive electronic pendulum, while distance traveled is measured by a calibrated fifth wheel in contact with the ground. The product of slope distance and the sine of the inclination angle is integrated continuously by a built-in electronic computer to yield the elevation differences.

In normal operations over good roads, the elevation meter may be driven at speeds up to 25 miles an hour. On soft or rough roads it is necessary to reduce the speed to protect the equipment and maintain accuracy. Average daily traverses range from 30 to 50 miles. Accuracies within 1 to 2 feet of elevation are readily attainable with proper planning and control.

Standards for pendulum alidades

The planetable alidade with a spirit-level bubble has been superseded by an alidade using a pendulum level datum. Two methods of reference to a level datum have been developed. The first was the Geological Survey's liquid-damped pendulum-alidade conversion unit, and the second was a commercial development, in cooperation with the Survey, of an air-damped self-indexing alidade. The selfindexing alidade has been adopted as the new standard alidade of the Survey, and more than 300 are now in use. The sensitivity of the level device, improved optics in the telescope, and magnified optical reading of the arc contribute to an indicated reproducibility of about 15 seconds of arc. The reproducibility of the spirit-level alidade is about 30 seconds of arc.

Field tests in 1961 planned by C. S. Maltby indicated that, with the proper precautions, lengths of inclined sights and the maximum angle of inclination may be increased over the limits imposed with the old standard alidade.

PHOTOGRAMMETRIC SURVEYS

Aerial-camera calibration

Aerial photography used in the compilation of topographic maps is procured from private contractors in accordance with the Geological Survey specifications. To ascertain whether the aerial cameras will perform satisfactorily in the Survey's photogrammetric system, it is necessary that each camera be checked on a camera calibrator designed by R. K. Bean and R. E. Ask.

The calibrator consists of an arrangement of 49 optical collimators whose axes converge upwards towards a central point. The camera to be tested is mounted on the calibrator so the lens is at the point of convergence. An image of each collimator target is formed in the camera focal plane and recorded on film. The angular positions of the collimators permit a pair of diapositives made from film exposed on the camera calibrator to be oriented in a plotting instrument. Stereoscopic measurements can be made on nine points in the model area to detect such defects in the photogrammetric system as lack of flatness of the camera-magazine platen, failure of the film-flattening system, and distortion in the camera, printer, or plotter lenses. Modification of the calibrator to permit testing of cameras equipped with super-wide-angle lenses is nearly complete. This modification consists of extending the angular field from 90° to 120°.

Super-wide-angle photogrammetric system

Super-wide-angle aerial cameras with angular coverage of 120° present challenging possibilities for economy in photogrammetric mapping. To investigate the applications of a super-wide-angle photogrammetric system to its operations, the Geological Survey has purchased from Wild Heerbrugg Instruments, Inc., two RC–9 cameras equipped with Super-Aviogon lenses. Procurement of super-wide-angle projectors has been initiated. Provisional standards for flight design to obtain super-wide-angle photography have been formulated, and a limited amount of orthophotography has been made from super-wide-angle photography in anticipation of possible future applications. Additional research and operational tests on super-wide-angle equipment are scheduled for 1963.

Half-base convergent photography

Half-base convergent photography is a modification of 20° twin-low-oblique convergent photography in which the base-height ratio is set at 0.62 instead of the standard ratio of 1.23. Edmund Swasey has made a study of the feasibility, limitations, and advantages of this type of photography and has found that the half-base stereoscopic model used with the ER–55 plotter is superior in illumination and resolution to the standard vertical or convergent model. An increase in the density of tree crown cover which can be tolerated has been demonstrated; for example, a 50-percent timber crown cover creates difficulties in contour placement with standard convergent photography, whereas 75 percent can be tolerated with the half-base photography.

Astronomic positions in Antarctica

During 1961 D. R. Lee and others evaluated the azimuth method of geographic-position determination as proposed by Ney[84] in order to improve astronomic-observing techniques. The method appeared applicable to the determination of astronomic positions in Antarctica where previous positions based on altitude measurements of the sun were influenced by the effects of uncertain variable refraction.

A series of daylight stellar observations made in the Washington area indicated that this method would yield results at least comparable with those attainable by altitude measurements on the stars, and superior to those attainable by round-the-clock altitude measurements on the sun. During the 1961–62 season, astronomic observations based on both azimuth and vertical-angle measurements were made at eight Antarctic stations. In addition to providing data on the effect of vertical refraction, it may be possible to use the separate solutions to evaluate the relative merits of the altitude or azimuth methods.

[84] Ney, C. H., 1954, Geographical positions from stellar azimuths: Am. Geophys. Union Trans., v. 35, no. 3, p. 391–397.

Contrast control for diapositives

J. G. Lewis has compared projected stereoimage characteristics produced with both undodged diapositives and diapositives prepared with two systems of dodging—electronic feedback and infrared quenching. Both dodging systems improved interpretability, but the infrared-quenching system proved to be slightly better. It was concluded that an automatic dodging system should be an integral part of the diapositive printers used by the Survey.

Analytical aerotriangulation

Several analytical-aerotriangulation systems are under development whereby high-speed electronic computers solve mathematical equations in establishing control points for map compilation. The photocoordinates of image points are observed on a precise comparator, and these coordinates, along with other pertinent data, comprise the input for computing the horizontal positions and elevations of the control points. A test of the "direct geodetic restraint" method of analytical aerotriangulation, using actual photographic and ground-control data, is reported by R. C. Eller and M. L. McKenzie (Art. 56) to demonstrate the potential of this method to perform acceptable aerotriangulation for use in topographic mapping.

Visual fatigue in photogrammetric operations

A pilot study of the visual problems of 10 selected stereocompilers was conducted in the Rocky Mountain Area office in 1958–59 under the direction of Wendell E. Bryan, O.D., Denver, Colo. The study reported by Dwyer[85] showed that visual refractive corrections and improved ambient illumination conditions resulted in generally improved operator efficiency and was reflected in higher production rates. A second project involving 60 Rocky Mountain Area stereocompilers is in progress, again under the direction of Bryan.

Orthophotography

Since the first orthophotographs (uniform-scale photographs) were produced in 1953, there has been gradual improvement in their accuracy and image quality, and substantial improvement in instruments and techniques for their production. The model U–60 orthophotoscope (Art. 57) was designed by R. K. Bean and others to be compatible with automatic photogrammetric-mapping systems. By the addition of synchromotors, profile data from each scan may be used, either simultaneously or subsequently, to operate image-resti-

[85] Dwyer, R. F., Jr., 1960, Visual factors in stereoscopic plotting: Photogrammetric Engineering, v. 26, no. 4, p. 557–564.

tution or model-carving equipment, and to extract hypsometric information in digital or analog form.

During 1962, a group headed by J. G. Lewis has been developing additional uses for orthophotography. The three principal areas of potential use are: (1) appraisal of the position accuracy of maps before revision, (2) a means of adding map features during revision or new mapping, and (3) a form of map substitute. Studies are in progress on scribing orthophotographs and on super-wide-angle orthophotographs.

Instrument development

Among the improvements in instrumentation during 1962 are the completion of the model T–61 orthophotoscope, the model E ER–55 projector, and a universal support assembly for stereoplotters.

The model T–61 orthophotoscope is a less complex unit than the U–60 (Art. 57) model, and consequently less expensive to manufacture. The prototype instrument will undergo operational testing during 1962.

The latest design in the ER–55 projector family, model E, is the product of cooperative efforts of engineers of Bausch & Lomb, Inc., and the Geological Survey. The major changes in the model E are: (1) addition of a thermostatic switch to prevent overheating; (2) a cast-aluminum reflector to replace the coated-plastic type; (3) a redesigned lens-canting mechanism to provide more positive action; and (4) improvements in the diapositive plateholder.

The universal support assembly is a basic structure that will accommodate various types of stereoplotting projectors that have projection distances ranging from 400 to 760 mm. Unique design features are structural rigidity, free support of a flat granite slab, and a universal pantograph mount. The electrical control system, suited to both ER–55 and Kelsh-type projectors, also provides automatic light-balance control.

CARTOGRAPHIC PROCEDURES

Edge isolation

With practical procedures available for the production of orthophotographs, development effort is being directed toward the use of enhanced photographic imagery as a map substitute or as a replacement for graphic symbols for certain types of map features. A promising photolaboratory technique leading toward these objectives has been developed by A. B. Clarke (Art. 166). In this procedure, called edge isolation, a film positive or print may be produced that has extremely opaque image edges, with other tonal graduations suppressed. The edge-isolated print is made by a semiautomatic two-step process, using the infrared quenching action of a photographic contact printer. The resulting product has many of the characteristics of a line print and it may be reproduced by lithography without screening. When the original is an orthophotograph, the edge-isolated print shows buildings, roads, woodland, and other features by line images in true position. Patterns useful to geologists and photointerpreters are often more easily identified than on a continuous-tone print.

Airbrush shading for ice features

Interest and activity in Antarctic mapping have resulted in the development of improved representation of various kinds of ice features by adapting the airbrush techniques of relief shading. Among the ice features depicted by shading, or a combination of shading and line symbols, are valley glaciers, wall-sided glaciers, channel glaciers, ice shorelines, meltwater lakes, ice cliffs, icebergs, ice shelves, hinge-line depressions, sastrugi, and crevasses. A group of the symbols and treatments developed by C. E. Grossman and others are used on current Antarctic mapping. These were submitted to the Working Group on Geodesy and Cartography of the Scientific Committee on Antarctic Research, by C. D. Whitmore, Chief Topographic Engineer.

Brown channel symbolization for desert terrain

In an effort to incorporate some of the graphic detail of aerial photographs into topographic maps, a procedure has been developed by R. E. Altenhofen and others for representing dry desert channels by a brown sand pattern. These channels are not adequately represented by contours in flat or gently sloping terrain, nor is it appropriate to show them by the blue drainage symbols. With the proposed procedure they can be traced from aerial photographs and depicted by a brown dot pattern, preserving the arid appearance of the topography. The procedure will be applied, for the most part, on maps of arid and semiarid regions of the West.

Map content and presentation

For the past 2 years a group headed by J. B. Rowland has been reviewing and revising the standards for selecting, classifying, and symbolizing features on topographic quadrangle maps. The objectives are to (1) improve the value of quadrangle maps by adding detail that is beneficial to map users, and (2) revise map treatment and symbolization to conform to modern compilation and cartographic techniques. These studies are based on a recent extensive survey of map uses, and on about 10 years of experience in map production under the present standards.

Revised standards resulting from this project have been issued for the mapping of buildings and populated places, fencelines, powerlines, and other linear features, industrial plant areas, mines and related features, geographic names, and boundaries. Studies are being made on revised standards for mapping roads, railroads, public-land subdivisions, hydrographic features, relief features, and woodland. In general, revised standards increase useful map content by the addition of permanent features of interest, and increase map accuracy by more precise and realistic symbols.

Relief models

A simple but effective procedure for constructing relief models from contour maps has been devised by Eugene Zang. The model is built up of plastic sheets, interleaved with map sections cut out along successive contour lines. The product is a more faithful rendition than the usual relief model, can be prepared without special skills or equipment, and gives a remarkable illusion of reality, particularly when shaded-relief maps are used. A model of the Ries Crater in Germany was constructed by this method for exhibit at the Geneva Conference for the Peaceful Uses of Outer Space.

U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

U.S. Geological Survey, Main Office, General Services Building, 18th and F Streets, N.W., Washington 25, D.C., Republic 7–1820.
U.S. Geological Survey, Rocky Mountain Center, Federal Center, Denver 25, Colorado, Belmont 3–3611.
U.S. Geological Survey, Pacific Coast Center, 345 Middlefield Road, Menlo Park, California, Davenport 5–6761.

PUBLIC INQUIRIES OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage	Margaret I. Erwin (Broadway 2–8791)	503 Cordova Building.
California, Los Angeles	Lucy E. Birdsall (Richmond 9–4711, ext. 1255)	1031 Bartlett Building, 215 West 7th Street.
California, San Francisco	Jean V. Molleskog (Yukon 6–3111, ext. 481)	232 Appraisers Building.
Colorado, Denver	Lorene C. Young (Keystone 4–4151, ext. 379)	468 New Custom House.
Utah, Salt Lake City	Maurine Clifford (Davis 8–2911, ext. 428)	437 Federal Building.
Texas, Dallas	Mary E. Reid (Riverside 8–5611, ext. 3230)	Room 602 Thomas Building, 1314 Wood Street.
Washington, Spokane	Eva M. Raymond (Temple 8–2084, ext. 30)	South 157 Howard Street.

GEOLOGIC DIVISION FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included]

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Alaska, College	Florence L. Weber (3263)	P.O. Box 4004; Brooks Memorial Building.
California, Los Angeles	John T. McGill (Granite 3–0971, ext. 9881)	Geology Building, University of California.
Hawaii, Hawaii National Park	James G. Moore	Hawaiian Volcano Observatory.
Hawaii, Honolulu	Charles G. Johnson	District Building 96, Fort Armstrong.
Kansas, Lawrence	William D. Johnson, Jr. (Viking 3–2700)	% State Geological Survey, Lindley Hall, University of Kansas.
Kentucky, Lexington	Paul W. Richards (4–2473)	496 Southland Drive.
Maryland, Beltsville	Sam H. Patterson (Tower 9–6430, ext. 470)	U.S. Geological Survey Building, Department of Agriculture Research Center.
Massachusetts, Boston	Lincoln R. Page (Kenmore 6–1444)	270 Dartmouth Street, Room 1.
Mississippi, Jackson	Esther R. Applin (Fleetwood 5–3223)	1202½ North State Street.
New Mexico, Albuquerque	Charles B. Read (Chapel 7–0311, ext. 483)	P.O. Box 4083, Station A; Geology Building, University of New Mexico.
Ohio, Columbus	James M. Schopf (Axminister 4–1810)	Orton Hall, Ohio State University, 155 South Oval Drive.
Ohio, New Philadelphia	James F. Pepper (4–2353)	P.O. Box 272; Muskingum Watershed Conservancy Building, 1319 Third Street, N.W.
Pennsylvania, Mt. Carmel	Jacques F. Robertson (339–4390)	P.O. Box 366; 56 West 2d Street.
Puerto Rico, Roosevelt	Watson H. Monroe (San Juan 6–5340)	P.O. Box 803.
Tennessee, Knoxville	Robert A. Laurence (2–7787)	11 Post Office Building.
Utah, Salt Lake City	Lowell S. Hilpert (Empire 4–2552)	231 East 4th Street, South.
Washington, Spokane	Albert E. Weissenborn (Temple 8–2084)	South 157 Howard Street.
Wisconsin, Madison	Carl E. Dutton (Alpine 5–3311, ext. 2128)	213 Science Hall, University of Wisconsin.
Wyoming, Laramie	William R. Keefer (Franklin 5–4495)	Geology Hall, University of Wyoming.

SELECTED LIST OF WATER RESOURCES DIVISION FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of February 3, 1962]

Location	*Official in charge* and telephone number*	*Address*
Alabama, University	William J. Powell (g) and Lamar E. Carroon (s), (Plaza 2–8104)	P.O. Box V; Building 6, Smith Woods, University of Alabama.
Alaska, Anchorage	Roger M. Waller (g), (Broadway 2–8333)	Room 501, Cordova Building, 555 Cordova Street.
Alaska, Juneau	Ralph E. Marsh (s), (Juniper 6–2815, ext. 61)	P.O. Box 2659; Room 111, 311 Fifth Street.
Alaska, Palmer	Robert G. Schupp (q), (Pioneer 5–3450)	P.O. Box 36, Wright Building.
Arizona, Phoenix	Herbert E. Skibitzke (g), (261–3456)	Room 4018, Federal Building, 230 North 1st Avenue.
Arizona, Tucson	P. Eldon Dennis (g) and Douglas D. Lewis (s), (Main 3–7731, ext. 291 and 294)	P.O. Box 4070; Geology Building, University of Arizona.
Arizona, Yuma	Charles C. McDonald (g), (Sunset 3–7841)	P.O. Box 1488; 16 West 2nd Street.
Arkansas, Little Rock	Richard T. Sniegocki (g), (Franklin 2–4361, ext. 270)	Room 2307, Federal Building.
	John H. Hubble (q), (Franklin 2–4361, ext. 219)	Room 2007, Federal Building.
	Ivan D. Yost (s), (Franklin 2–4361, ext. 246)	Room 2301, Federal Building.
California, Sacramento	Fred Kunkel (g), (449–2563) and Eugene Brown (q), (449–3174)	Room 8024, Federal Building, 650 Capitol Avenue.
Connecticut, Hartford	John Horton (s), (Jackson 7–3281, ext. 257)	P.O. Box 715; Room 203, Federal Building.
Connecticut, Middletown	John A. Baker (g), (Diamond 6–6986)	Room 204, Post Office Building.
Delaware, Dover	Philip P. Fannebecker (s), (Redfield 4–2506)	P.O. Box 707, 604 Fairview Avenue.
Delaware, Newark	Donald R. Rima (g), (Endicott 8–1197)	P.O. Box 24; 92 East Main Street.
Florida, Ocala	Kenneth A. MacKichan (q) and Archibald O. Patterson (s), (Marion 2–6513)	Room 244, Federal Building.
Florida, Tallahassee	Clyde S. Conover (g), (223–1693, 223–2636)	P.O. Drawer 110, Gunter Building (corner of Tennessee and Woodward Streets).
Georgia, Atlanta	Harlan B. Counts (g), (Murray 8–5996)	Room 416, 19 Hunter Street, South West.
	Albert N. Cameron (s), (Trinity 6–3311, ext. 5218)	Room 609, 805 Peachtree Street Building.
Hawaii, Honolulu	Dan A. Davis (g), (58–831, ext. 260, 261)	Room 332, First Insurance Building, 1100 Ward Avenue.
	Howard S. Leak (s), (58–831, ext. 251)	Room 330, First Insurance Building, 1100 Ward Avenue.
Idaho, Boise	Wayne I. Travis (s), (344–4031)	Room 215, 914 Jefferson Street.
	Maurice J. Mundorff (g), (342–5441)	Room 205, 914 Jefferson Street.
Illinois, Champaign	William D. Mitchell (s), (Fleetwood 6–5221)	605 South Neil Street.
Indiana, Indianapolis	Malcolm D. Hale (s), (Melrose 8–5541) and Claude M. Roberts (g), (Melrose 2–1457)	Room 407, 611 North Park Avenue.
Iowa, Iowa City	Vernal R. Bennion (s), (337–9345)	508 Hydraulic Laboratory.
	Walter L. Steinhilber (g), (338–1173)	Geology Annex-State University of Iowa.
Kansas, Lawrence	Vinton C. Fishel (g), (Lawrence 2700, ext. 559)	c/o University of Kansas.
Kansas, Topeka	Edward J. Kennedy (s), (Central 3–0521)	P.O. Box 856; Room 403, Federal Building.
Kentucky, Louisville	Robert V. Cushman (g) and Floyd F. Schrader (s), (Juniper 4–1361, ext. 8235 and 8236)	Room 310, Center Building, 522 West Jefferson Street.
Louisiana, Baton Rouge	Fay N. Hansen (s), (924–4215)	Room 215, Prudential Building, 6554 Florida Boulevard.
	Stanley F. Kapustka (q), (924–4215)	Room 201, Prudential Building, 6554 Florida Boulevard.
	Rex R. Meyer (g), (Dickens 3–2873)	P.O. Box 8516; University Station, Room 43, Atkinson Hall, Louisiana State University.

*The small letter in parentheses following each official's name signifies his branch affiliation in the Water Resources Division as follows: g—Ground Water Branch; q—Quality of Water Branch; s—Surface Water Branch; h—General Hydrology Branch.

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Maryland, Baltimore	Edmond G. Otton (g), (Belmont 5–0771)	Room 103, Latrobe Hall, The Johns Hopkins University.
Maryland, College Park	Leslie W. Lenfest (s), (Warfield 7–6348)	P.O. Box 37; Room 106, Engineering Classroom Building, University of Maryland.
Maryland, Rockville	John W. Wark (q), (Poplar 2–2885)	Room 3, Abbey Building, 3 North Perry Street.
Massachusetts, Boston	Richard G. Petersen (g), (Capitol 3–2725)	Room 847, Oliver Building, 141 Milk Street.
	Charles E. Knox (s), (Capitol 3–2726)	Room 845, Oliver Building, 141 Milk Street.
Michigan, Lansing	Arlington D. Ash (s), (Ivanhoe 9–2431) and Morris Deutsch (g), (Ivanhoe 9–7913)	Room 407, Capitol Savings and Loan Building.
Minnesota, St. Paul	Leon R. Sawyer (s), (Capitol 2–8011, ext. 265)	Room 1610, New Post Office Building.
	Richmond F. Brown (g) (Capitol 2–8011, ext. 260)	Room 1002, New Post Office Building.
Mississippi, Jackson	Joe W. Lang (g), (Fleetwood 5–2724) and William H. Robinson (s), Fleetwood 2–2718)	P.O. Box 2052; Room 300, U.S. Post Office Building.
Missouri, Rolla	Harry C. Bolon (s), (Emerson 4–1599)	P.O. Box 138; 900 Pine Street.
Missouri, St. Louis	James W. Geurin (q) and Harry D. Wilson (g), (Main 1–8100 Sta 2361)	Room 728, U.S. Courthouse and Customs House, 1114 Market Street.
Montana, Billings	Frank A. Swenson (g), (Alpine 9–2412)	P.O. Box 1818; Rooms 201, 202, 212, 1 North 7th Street West.
Montana, Helena	Frank Stermitz (s), (442–4890)	P.O. Box 1696; Room 409, Federal Building.
Nebraska, Lincoln	Don M. Culbertson (q), Charles F. Keech (g), and Floyd F. Lefever (s), (Hemlock 5–3273, ext. 346, 323, and 328)	Room 132, Nebraska Hall, 901 North 17th Street.
Nevada, Carson City	Edwin E. Harris (s) and Glenn T. Malmberg (g), (Granite 2–1583)	P.O. Box B; 809 North Plaza Street.
New Jersey, Trenton	John E. McCall (s), (Export 4–5301, ext. 214)	P.O. Box 967; Room 433, Federal Building.
	Allen Sinnott (g), (Export 4–5301, ext. 213)	P.O. Box 1238; Room 432, Federal Building.
New Mexico, Albuquerque	William E. Hale (g) and Jay M. Stow (q), (Chapel 7–0311, ext. 2248 and 2249)	P.O. Box 4217; Geology Building, University of New Mexico.
New Mexico, Santa Fe	Wilbur L. Heckler (s), (Yucca 2–1921)	P.O. Box 277; Room 224, Federal Courthouse.
New York, Albany	Ralph C. Heath (g), Donald F. Dougherty (s), Felix H. Pauszek (q), (Hobart 3–5581)	P.O. Box 948; Rooms 342, 343, 348, Federal Building.
North Carolina, Raleigh	Granville A. Billingsley (q) and Philip M. Brown (g), (828–4345); Edward B. Rice (s), (834–6427)	P.O. Box 2857; 4th Floor, Federal Building.
North Dakota, Bismarck	Harlan M. Erskine (s), (Capitol 3–3525)	P.O. Box 750; Room 7, 202½ 3rd Street.
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	George W. Whetstone (q), (Belmont 1–7553)	2822 East Main Street.
	Stanley E. Norris (g), (Capital 1–6411, ext. 281)	Room 554, U.S. Post Office Building, 85 Marconi Boulevard.
Oklahoma, Oklahoma City	Alvin R. Leonard (g), (Central 6–2311, ext. 412)	Room 4011, Federal Building, 200 Northwest 4th Street.
	Richard P. Orth (q), (Orange 7–5022)	P.O. Box 4355; 2800 South Eastern.
	Alexander A. Fischback, Jr. (s), (Central 6–2311, ext. 257)	Room 4301, Federal Building, 1101 North Broadway.

*The small letter in parentheses following each official's name signifies his branch affiliation in the Water Resources Division as follows: g—Ground Water Branch; q—Quality of Water Branch; s—Surface Water Branch; h—General Hydrology Branch.

SELECTED LIST OF WATER RESOURCES DIVISION FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO—Continued

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Pennsylvania, Harrisburg	Joseph E. Barclay (g), (Cedar 8-4925)	100 North Cameron Street.
	Robert E. Steacy (s), (Cedar 8-5151, ext. 2724)	P.O. Box 421; 1224 Mulberry Street.
Pennsylvania, Philadelphia	Norman H. Beamer (q), (Market 7-6000, ext. 274)	Room 1302, U.S. Custom House, 2nd and Chestnut Streets.
Puerto Rico, San Juan	Dean B. Bogart (s), (723-3989)	1209 Fernández Juncos Avenue, Santurce.
Rhode Island, Providence	William B. Allen (g), (Dexter 1-9312)	Room 401-2, Federal Building, U.S. Post Office.
South Carolina, Columbia	Albert E. Johnson (s), (Alpine 2-2449)	Room 210, Creason Building, 1247 Sumter Street.
	George E. Siple (g), (Alpine 3-7478)	P.O. Box 5314; 627 Bull Street.
South Dakota, Huron	John E. Powell (g), (Elgyn 2-3756)	P.O. Box 1412; Room 231, Federal Building.
South Dakota, Pierre	John E. Wagar (s), (Capital 4-7856)	P.O. Box 216; Room 207, Federal Building.
Tennessee, Chattanooga	Joseph S. Cragwall, Jr. (s), (Amherst 6-2725)	Room 823, Edney Building.
Tennessee, Memphis	Elliott M. Cushing (g), (Fairfax 3-4841)	Memphis General Depot, U.S. Army.
Tennessee, Nashville	Joe L. Poole (g), (Cypress 8-2849)	90 White Bridge Road.
Texas, Austin	Charles H. Hembree (q), Allen G. Winslow (g), and Trigg Twichell (s), (Greenwood 6-6411)	Vaughn Building, 807 Brazos Street.
Utah, Salt Lake City	Russell H. Langford (q), (Davis 2-3711)	P.O. Box 2657; Building 504, Fort Douglas.
	Ted Arnow (g), (Davis 8-2911, ext. 436)	Room 125, Empire Building, 231 East 4th South.
	Milton T. Wilson (s), (Davis 8-2911, ext. 434)	Room 130, Empire Building, 231 East 4th South.
Virginia, Charlottesville	James W. Gambrell (s), (293-2127)	P.O. Box 3327; University Station Natural Resources Building, McCormick Road.
Washington, Tacoma	Arthur A. Garrett (g), (Greenfield 4-4261)	3020 South 38th Street.
	Fred M. Veatch (s), (Fulton 3-1491)	Room 207 Federal Building.
West Virginia, Charleston	Warwick L. Doll (s), (343-6181, ext. 311)	3303 New Federal Office Building, 500 Quarrier Street East.
West Virginia, Morgantown	Gerald Meyer (g), (Linden 2-8103)	University of West Virginia, 405 Mineral Industries Building.
Wisconsin, Madison	Charles R. Holt Jr. (g), (Alpine 5-3311), ext. 2329)	Room 175 Science Hall, University of Wisconsin.
	Kenneth B. Young (s), (Alpine 6-4411, ext. 494)	Room 699, State Office Building.
Wyoming, Casper	George L. Haynes, Jr. (s), (234-6339)	P.O. Box 442; 150 South Jackson.
Wyoming, Cheyenne	Ellis D. Gordon (g) and Leon A. Wiard (s), (634-2731, ext. 37 and 23)	P.O. Box 177; Frangos Building, 2121 Carey Avenue.
Wyoming, Worland	Thomas F. Hanly (q), (Fireside 7-2181)	1214 Big Horn Avenue.

*The small letter in parentheses following each official's name signifies his branch affiliation in the Water Resources Division as follows: g—Ground Water Branch; q—Quality of Water Branch; s—Surface Water Branch; h—General Hydrology Branch.

GEOLOGICAL SURVEY OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

[List current as of September 1, 1962]

Location	*Geologist in charge*	*Mailing address*
Bolivia, La Paz	Charles M. Tschanz	U.S. Geological Survey, US AID Mission, c/o American Embassy, La Paz, Bolivia.
Brazil, Rio de Janeiro	Alfred J. Bodenlos	U.S. Geological Survey, US AID Mission, c/o American Embassy, APO 676, New York, New York.
Chile, Santiago	William D. Carter	U.S. Geological Survey, c/o American Embassy, Santiago, Chile.
Germany, Heidelburg	Jerald M. Goldberg	U.S. Geological Survey Team Representative (Europe), Engineer Intelligence Center, APO 403, New York, New York.
Indonesia, Bandung	Robert F. Johnson	U.S. Geological Survey, US AID Mission, c/o American Embassy, Djakarta, Indonesia.
Mexico, México, D. F.	Charles T. Pierson	U.S. Geological Survey, US AID Mission, c/o American Embassy, México, D. F., Mexico.
Pakistan, Quetta	John A. Reinemund	U.S. Geological Survey, US AID Mission, c/o American Embassy, APO 271, New York, New York.
Philippines, Manila	Joseph F. Harrington	U.S. Geological Survey, c/o American Embassy, APO 928, San Francisco, California.
Thailand, Bangkok	Louis S. Gardner	U.S. Geological Survey, c/o American Embassy, APO 146, Box B, San Francisco, California.

WATER RESOURCES DIVISION

[List current as of September 1, 1962]

Location	*Official in charge*	*Mailing address*
Afghanistan, Kabul	Robert H. Brigham	U.S. Geological Survey, Lashkar Gah, c/o American Embassy, Kabul, Afghanistan.
Belgium, Mol	Eugene S. Simpson	U.S. Geological Survey, Waste-Disposal Service Center, Mol-Donk.
Brazil, Rio de Janeiro	Dagfin J. Cederstrom	U.S. Geological Survey, APO 676, c/o Postmaster, New York, New York.
Chile, Santiago	William W. Doyel	U.S. Geological Survey, c/o American Embassy, Chile, Department of State Mail Room, Washington 25, D.C.
Iran, Tehran	Alvin F. Pendleton	U.S. Geological Survey, US AID Mission, c/o American Embassy, APO 205, New York, New York.
Libya, Benghazi	James R. Jones	U.S. Geological Survey, USOM, APO 231 (Box B), New York, New York.
Nepal, Katmandu	Daniel E. Havelka	U.S. Geological Survey, US AID Mission, APO 143, San Francisco, California.
Pakistan, Lahore	Maurice J. Mundorff	U.S. Geological Survey, US AID Mission, APO 271, New York, New York.
Sudan, Khartoum	Harry G. Rodis	U.S. Geological Survey, US AID Mission, Sudan, c/o American Embassy, Department of State Mail Room, Washington 25, D.C.
Tunisia, Tunis	Lee C. Dutcher	U.S. Geological Survey, US AID Mission, Tunisia, c/o American Embassy, Department of State Mail Room, Washington 25, D.C.
Turkey, Ankara	Leonard J. Snell	U.S. Geological Survey, c/o US AID Mission, APO 254, New York, New York.
United Arab Republic, Cairo	Raymond W. Sundstrom	U.S. Geological Survey, US AID Mission, Cairo, c/o Department of State Mail Room, Washington 25, D.C.

COOPERATING AGENCIES

FEDERAL AGENCIES

Agency for International Development
Agricultural Research Service
Air Force:
- Cambridge Research Center
- Technical Application Center

Army:
- Corps of Engineers

Atomic Energy Commission:
- Division of Biology and Medicine
- Division of Isotope Development
- Division of Reactor Development
- Military Application Division
- Raw Materials Division
- Research Division
- Special Projects Division

Bonneville Power Administration
Bureau of Commercial Fisheries
Bureau of Indian Affairs
Bureau of Land Management
Bureau of Mines
Bureau of Public Roads
Bureau of Reclamation
Bureau of Sport Fisheries and Wildlife
Coast Guard
Department of Defense:
- Advanced Research Projects Agency

Department of Justice
Department of State
District of Columbia, Government of
Federal Housing Administration
Federal Power Commission
Forest Service
Maritime Administration
National Park Service
Navy:
- Bureau of Yards and Docks
- Office of Naval Research
- Ordnance Test Station
- Pacific Missile Range

National Aeronautical and Space Administration
National Science Foundation
Office of Minerals Exploration
Outdoor Recreation Committee
Public Health Service
Soil Conservation Service
Tennessee Valley Authority
U.S. Study Commissions—Southeast River Basins
Veterans Administration
Weather Bureau

STATE, COUNTY, AND MUNICIPAL AGENCIES

Alabama:
- Geological Survey of Alabama
- Alabama Highway Department
- Department of Conservation
- Water Improvement Commission
- Calhoun County Board of Revenue
- Mobile County
- Tuscaloosa County Board of Revenue
- City of Huntsville
- City of Russellville Water Board

Alaska:
- Alaska Department of Natural Resources
- Alaska Department of Health

Arizona:
- State Land Department
- Regents of the University of Arizona
- Superior Court, County of Apache, Arizona
- Maricopa County Flood Control District
- Maricopa County Municipal Water Conservation District No. 1
- City of Flagstaff
- City of Tucson
- Navajo Tribal Council
- Buckeye Irrigation Company
- Gila Valley Irrigation District
- Salt River Valley Water Users Association
- San Carlos Irrigation and Drainage District

Arkansas:
- Arkansas Game and Fish Commission
- Arkansas Geological and Conservation Commission
- Arkansas State Highway Commission

Arkansas—Continued
- University of Arkansas:
  - Agricultural Experiment Station
  - Engineering Experiment Station

California:
- California Department of Natural Resources, Division of Mines
- State Department of Fish and Game
- State Department of Water Resources
- Alameda County Water District
- Calaveras County Water District
- County of Los Angeles Department of County Engineers
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- North Marin County Water District
- Orange County Flood Control District
- San Benito County
- Santa Barbara County Water Agency
- Santa Clara County Flood Control and Water Conservation District
- Santa Cruz County Flood and Water Conservation District
- City of Arcata
- City of San Diego
- San Francisco Water Department
- San Luis Obispo Flood Control and Water Conservation District
- Santa Barbara Water Department
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Hetch Hetchy Water Supply

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STATE, COUNTY, AND MUNICIPAL AGENCIES—Continued

California—Continued
- Imperial Irrigation District
- Metropolitan Water District of Southern California
- Palo Verde Irrigation District
- San Bernardino Valley Water Conservation District
- Santa Maria Valley Water Conservation District
- Ventura River Municipal Water District

Colorado:
- Department of Natural Resources
- Office of State Engineer, Division of Water Resources
- Colorado State Metal Mining Fund Board
- Colorado Water Conservation Board
- Colorado Agricultural Experiment Station
- Board of County Commissioners, Boulder County
- Colorado Springs—Department of Public Utilities
- Denver Board of Water Commissioners
- Arkansas River Compact Administration
- Colorado River Water Conservation District
- Rio Grande Compact Commission
- Southeastern Colorado Water Conservancy District

Connecticut:
- Connecticut Geological and Natural History Survey
- State Highway Department
- State Water Resources Commission
- Greater Hartford Flood Commission
- Hartford Department of Public Works
- New Britain Board of Water Commissioners
- Engineering Department—City of Torrington

Delaware:
- Delaware Geological Survey
- State Highway Department

District of Columbia:
- District of Columbia Department of Sanitary Engineering

Florida:
- Florida Geological Survey
- State Board of Parks and Historic Memorials
- State Road Department of Florida
- Broward County—Board of County Commissioners
- Collier County—Board of County Commissioners
- Dade County—Board of County Commissioners
- Hillsborough County—Board of County Commissioners
- Orange County—Board of County Commissioners
- Pinellas County—Board of County Commissioners
- Polk County—Board of County Commissioners
- City of Fort Lauderdale
- City of Jacksonville, Office of the City Engineer
- City of Jacksonville, City Commission
- City of Miami—Department of Water and Sewerage
- City of Miami Beach
- City of Naples
- City of Pensacola
- City of Perry
- City of Pompano Beach
- City of Tallahassee
- Central and Southern Florida Flood Control District
- Trustees of Internal Improvement Fund

Georgia:
- State Division of Conservation, Department of Mines, Mining and Geology
- State Highway Department

Hawaii:
- State Department of Land and Natural Resources
- Honolulu, City and County of

Idaho:
- Idaho Department of Highways
- Idaho Department of Reclamation

Illinois:
- State Department of Public Works and Buildings:
  - Division of Highways
  - Division of Waterways
- State Department of Registration and Education
- Cook County Department of Highways
- Fountain Head Drainage District
- Northwest Illinois Metropolitan Planning Commission

Indiana:
- State Department of Conservation—Division of Water Resources
- State Highway Commission

Iowa:
- Iowa Geological Survey
- Iowa State Conservation Commission
- Iowa Natural Resources Council
- Iowa State Highway Commission
- Iowa Institute of Hydraulic Research
- Iowa State University—Agricultural Experiment Station
- Linn County—Board of Supervisors
- City of Fort Dodge—Department of Utilities

Kansas:
- State Geological Survey of Kansas, University of Kansas
- State Board of Agriculture, Division of Water Resources
- State Board of Health
- State Highway Commission
- State Water Resources Board
- City of Wichita:
  - Water Supply and Sewage Treatment Division
  - Metropolitan Area Planning Department

Kentucky:
- Kentucky Geological Survey, University of Kentucky

Louisiana:
- State Geological Survey
- State Department of Conservation
- State Department of Highways
- State Department of Public Works
- Sabine River Compact Commission

Maine:
- Maine Public Utilities Commission

Maryland:
- State Department of Geology, Mines, and Water Resources
- Maryland National Capital Park and Planning Commission
- Commissioners of Charles County
- City of Baltimore
- Washington Suburban Sanitary Commission

Massachusetts:
- State Department of Public Works:
  - Division of Waterways
  - Division of Highways
- Massachusetts Water Resources Commission
- Boston Metropolitan District Commission

STATE, COUNTY, AND MUNICIPAL AGENCIES—Continued

Michigan:
- Department of Conservation, Geological Survey Division
- State Highway Department
- State Water Resource Commission

Minnesota:
- State Department of Conservation, Division of Waters
- State of Minnesota Department of Highways
- Board of County Commissioners of Hennepin County
- Department of Iron Range Resources and Rehabilitation

Mississippi:
- Mississippi Board of Water Commissioners
- Mississippi State Highway Department
- Jackson County, Mississippi, Port Authority
- City of Corinth
- City of Jackson
- Mississippi Industrial and Technological Research Commission

Missouri:
- Division of Geological Survey and Water Resources
- Missouri State Highway Commission
- Curators of the University of Missouri

Montana:
- Montana Bureau of Mines and Geology
- State Engineer
- State Fish and Game Commission
- State Highway Commission
- State Water Conservation Board

Nebraska:
- Department of Water Resources
- Department of Roads
- University of Nebraska—Conservation and Survey Division
- Nebraska Mid-State Reclamation District
- Sanitary District Number One of Lancaster County

Nevada:
- Nevada Bureau of Mines, University of Nevada
- Department of Conservation and Natural Resources
- Department of Highways

New Hampshire:
- New Hampshire Water Resources Board

New Jersey:
- Department of Agriculture
- State Department of Conservation and Economic Development
- Department of Health
- Rutgers University, the State University of New Jersey
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission

New Mexico:
- State Engineer and School of Mines
- State Highway Department
- New Mexico Institute of Mining and Technology
- Interstate Stream Commission
- Pecos River Commission
- Pecos Valley Artesian Conservation District
- Rio Grande Compact Commission

New York:
- State Conservation Department
- State Department of Commerce
- State Department of Health
- State Department of Public Works
- New York Water Resources Commission

New York—Continued
- Board of Hudson River–Black River Regulating District
- County of Dutchess—Dutchess County Board of Supervisors
- County of Nassau—Department of Public Works
- Onondaga County Public Works Commission
- Onondaga County Water Authority
- Rockland County Board of Supervisors
- Suffolk County Board of Supervisors
- County of Suffolk—Suffolk County Water Authority
- County of Westchester—Department of Public Works
- City of Albany—Department of Water and Water Supply
- City of Auburn—Water Department
- City of Jamestown—Board of Public Utilities
- New York City Board of Water Supply
- New York City Department of Water Supply; Gas and Electricity
- Village of Nyack—Board of Water Commissioners
- Schenectady Water Department
- Brighton Sewer District #2
- Oswegatchie-Cranberry Reservoir Commission

North Carolina:
- North Carolina Department of Conservation and Development
- State Department of Water Resources
- State Highway Commission
- Martin County—Board of County Commissioners
- City of Asheville
- City of Burlington
- City of Carey
- City of Charlotte
- City of Durham
- City of Greensboro
- City of Waynesville

North Dakota:
- North Dakota Geological Survey
- State Highway Department
- State Water Conservation Commission

Ohio:
- Ohio Department of Health
- Ohio Department of Highways
- Ohio Department of Natural Resources:
  - Division of Geological Survey
  - Division of Water
- City of Columbus—Department of Public Service
- Miami Conservancy District
- Ohio River Valley Water Sanitation Commission

Oklahoma:
- Oklahoma State Department of Health
- Oklahoma Water Resources Board
- Oklahoma City Water Department

Oregon:
- Oregon Agricultural Experiment Station
- State Engineer
- State Highway Department
- Board of Higher Education
- Oregon State College—Department of Fish and Game Management
- Oregon State Sanitary Authority
- Oregon Water Resources Department
- County Court of Douglas County

STATE, COUNTY, AND MUNICIPAL AGENCIES—Continued

Oregon—Continued
- County Court of Josephine County
- County Court of Lane County
- County Court of Morrow County
- City of Dallas
- City of Dalles City
- City of Eugene—Water and Electric Board
- City of McMinnville—Water and Light Department
- City of Portland
- City of Toledo
- Coos Bay North Bend Water Board
- Talent Irrigation District

Pennsylvania:
- Bureau of Topographic and Geologic Survey, Department of Internal Affairs
- State Department of Agriculture
- State Department of Forests and Waters
- State Department of Health
- City of Bethlehem
- City of Harrisburg
- City of Philadelphia
- Conestoga Valley Association, Inc.

Rhode Island:
- State of Rhode Island and Providence Plantations
- Rhode Island Water Resources Coordinating Board
- State Department of Public Works—Division of Harbors and Rivers

South Carolina:
- State Development Board
- State Highway Department
- State Public Service Authority
- State Water Pollution Control Authority
- City of Spartanburg—Public Works Department

South Dakota:
- State Geological Survey
- South Dakota Department of Highways
- South Dakota Water Resources Commission

Tennessee:
- Tennessee Department of Conservation and Commerce:
  - Division of Geology
  - Division of Water Resources
- Tennessee Game and Fish Commission
- Tennessee Department of Highways and Public Works
- Tennessee Department of Public Health—Stream Pollution Control
- City of Chattanooga
- Memphis Board of Light, Gas, and Water Commissioners, Water Division

Texas:
- Texas Department of Agriculture
- Texas A & M Research Foundation
- Texas Water Commission
- Pecos River Commission
- Rio Grande Compact Commission
- Sabine River Compact Administration
- City of Dallas

Utah:
- Utah State Engineer
- Utah Water and Power Board
- State Department of Fish and Game
- State Road Commission of Utah
- University of Utah

Utah—Continued
- Salt Lake County
- Bear River Compact Commission

Vermont:
- State Water Resources Board

Virginia:
- Department of Highways
- County of Chesterfield
- County of Fairfax
- City of Alexandria
- City of Charlottesville
- City of Newport News—Department of Public Utilities
- City of Norfolk—Division of Water Supply
- City of Roanoke
- City of Staunton

Washington:
- State Department of Conservation:
  - Division of Mines and Geology
  - Division of Water Resources
- State Department of Fisheries
- State Department of Game
- State Department of Highways
- State Pollution Control Commission
- Municipality of Metropolitan Seattle
- City of Seattle
- City of Tacoma

West Virginia:
- State Conservation Commission
- State Geological and Economic Survey
- State Road Commission
- State Water Resources Commission
- Clarksburg Water Board

Wisconsin:
- Wisconsin Conservation Department
- Wisconsin Geological and Natural History Survey, University of Wisconsin
- State Highway Commission
- Public Service Commission of Wisconsin
- State Committee on Water Pollution
- Madison Metropolitan Sewerage District

Wyoming:
- Geological Survey of Wyoming
- State Engineer's Office
- Wyoming Highway Department
- Wyoming Natural Resource Board
- City of Cheyenne—Board of Public Utilities

Commonwealth:
- Puerto Rico:
  - Aqueduct and Sewer Authority
  - Department of Public Works
  - Economic Development Administration
  - Industrial Development Company
  - Water Resources Authority

Unincorporated Territories:
- American Samoa:
  - Government of American Samoa
- Guam:
  - Government of Guam
- Virgin Islands of the United States:
  - Government of the Virgin Islands

INVESTIGATIONS IN PROGRESS IN THE GEOLOGIC AND WATER RESOURCES DIVISIONS

Investigations in progress in the Geologic and Water Resources Divisions during the fiscal year 1962 are listed below, together with the names and headquarters of the individuals in charge of each. The list includes some projects that have been completed except for publication of final results, and a few that have been temporarily recessed. Headquarters for major offices are indicated by the initials (W) for Washington, D.C., (D) Denver, Colo., and (M) for Menlo Park, Calif. Headquarters in other cities are indicated by name; see list of offices on preceding pages for addresses. For projects in the Water Resources Division, a lowercase letter before the city initial or name indicates the unit under which the project is administered: g, Branch of Ground Water; s, Branch of Surface Water; q, Branch of Quality of Water; h, Branch of General Hydrology; and w, Water Resources Division.

Projects that include a significant amount of geologic mapping are indicated by asterisks. One asterisk (*) indicates mapping at a scale of a mile to the inch or larger, and two asterisks (**) indicate mapping at a scale smaller than a mile to the inch.

The projects are classified by State or similar unit and are repeated as necessary to show work in more than one State. However, projects that deal with areas involving four or more States are listed only under the heading "Large Regions of the United States."

Topical investigations, such as commodity studies and studies of geologic and hydrologic processes and methods, are listed under the single most appropriate topical heading, even though the work may deal with more than one subject. Topical investigations that involve specific areas are also listed under regional headings.

REGIONAL INVESTIGATIONS

Large regions of the United States:
- Geologic map of the United States
  - P. B. King (M)
- Gravity map of the United States
  - H. R. Joesting (W)
- Paleotectonic map folio—Permian System
  - E. D. McKee (D)
- Paleotectonic map folio—Mississippian System
  - L. C. Craig (D)
- Paleotectonic map folio—Pennsylvanian System
  - E. D. McKee (D)
- Bibliography of North American geology
  - M. Cooper (W)
- Subsurface-data center
  - L. C. Craig (D)
- Correlation of airborne radioactivity data and areal geology
  - J. A. Pitkin (W)
- Cross-country aeromagnetic profiles
  - E. R. King (W)
- Synthesis of geologic data on Atlantic Coastal Plain and Continental Shelf
  - J. E. Johnston (W)
- Geology of the Piedmont region of the Southeastern States (monazite)
  - W. C. Overstreet (W)
- Igneous rocks of Southeastern United States
  - C. Milton (W)
- Geology of the Appalachian Basin with reference to disposal of high-level radioactive wastes
  - G. W. Colton (W)
- Aerial radiological monitoring surveys, Northeastern United States
  - P. Popenoe (W)
- Middle and Late Tertiary history of parts of the Northern Rocky Mountains and Great Plains
  - N. M. Denson (D)
- Mesozoic stratigraphic paleontology, Pacific coast
  - D. L. Jones (M)

Large regions of the United States—Continued
- Cretaceous stratigraphy and paleontology, western interior United States
  - W. A. Cobban (D)
- Jurassic stratigraphic paleontology of North America
  - R. W. Imlay (W)
- Midcontinent Devonian investigations
  - E. R. Landis (D)
- Silurian and Devonian stratigraphic paleontology of the Great Basin and Pacific coast
  - C. W. Merriam (W)
- Ordovician stratigraphic paleontology of the Great Basin and Rocky Mountains
  - R. J. Ross, Jr. (D)
- Thermal pollution of streams
  - G. E. Harbeck (h. D)
- Changes below dams (river channels)
  - M. G. Wolman (h, Baltimore)
- Hydrology of the public domain
  - H. V. Peterson (h, M)
- Fluvial denudation in the United States
  - A. W. Gambell, Jr. (q, Arlington, Va.)
- General studies of erosion and sedimentation
  - G. G. Parker (h, D)
- Effect of mechanical treatment on arid land in the Western United States
  - F. A. Branson (h, D)
- Chemical characteristics of larger public water supplies in the United States
  - C. N. Durfor (q, W)
- Geohydrology of the Mississippi Embayment
  - W. J. Wellborne (q, Fayetteville, Ark.)
- Collection of basic records on chemical quality and sediment of surface waters of the United States
  - S. K. Love (q, W)
- Variance in water quality and environment
  - A. W. Gambell, Jr. (q, Arlington, Va.)

Large regions of the United States—Continued
Reconnaissance of fluvial sediment in the Potomac River basin
J. W. Wark (q, Rockville, Md.)
Water-supply exploration on the public domain (Western States)
N. J. King (g, D)
Summary of the ground-water situation in the United States
C. L. McGuinness (g, W)
Geochemistry of water in carbonate rocks
W. Back (g, W)
Geology and hydrology of the Central and Northeastern States as related to the management of radioactive materials
W. C. Rasmussen (g, Newark, Del.)
Mississippi Embayment hydrology
E. M. Cushing (g, Memphis, Tenn.)
Geology and hydrology of Great Plains States as related to the management of radioactive materials
W. C. Rasmussen (g, Newark, Del.)
Geology and hydrology of the Western States as related to the management of radioactive materials
R. W. Maclay (g, St. Paul, Minn.)

Alabama:
Coal resources
W. C. Culbertson (D)
Clinton iron ores of the southern Appalachians
R. P. Sheldon (D)
Pre-Selma Cretaceous rocks of Alabama and adjacent states
L. C. Conant (Tripoli, Libya)
Mesozoic rocks of Florida and the eastern Gulf coast
E. R. Applin (Jackson, Miss.)
*Warrior quadrangle, (coal)
W. C. Culbertson (D)
Geomorphology of Russell Cave
J. T. Hack (W)
Subsurface geologic study of Alabama
W. J. Powell (g, Tuscaloosa, Ala.)
Limestone-terrane hydrology
F. A. Swenson (g, D)
Artesian water in Tertiary limestones in Florida, southern Georgia, and adjacent parts of Alabama and South Carolina
V. T. Stringfield (w, W)
Precipitation records
L. E. Carroon (s, Tuscaloosa, Ala.)
Stream profiles (surface water)
L. B. Peirce (s, Tuscaloosa, Ala.)
Reconnaissance of chemical quality of Alabama streams
R. N. Cherry (q, Ocala, Fla.)
Flood gaging
L. E. Carroon (s, Tuscaloosa, Ala.)
Local floods
L. B. Peirce (s, Tuscaloosa, Ala.)
Temperatures of lake waters
L. E. Carroon (s, Tuscaloosa, Ala.)
Unit graphs and infiltration rates (surface water)
L. B. Peirce (s, Tuscaloosa, Ala.)
Bridge-site studies (water)
L. B. Peirce (s, Tuscaloosa, Ala.)
Geologic and hydrologic profile along the Chattahoochee River
L. D. Toulmin (g, Tuscaloosa, Ala.)

Alabama—Continued
Autauga County (ground water)
J. C. Scott (g, Tuscaloosa, Ala.)
Bullock County (ground water)
J. C. Scott (g, Tuscaloosa, Ala.)
Calhoun County (ground water)
J. C. Warman (g, Tuscaloosa, Ala.)
Cherokee County (ground water)
L. V. Causey (g, Tuscaloosa, Ala.)
Calhoun County surface-water resources
J. R. Harkins (s, Tuscaloosa, Ala.)
Geologic and hydrologic profiles in Clarke County
L. D. Toulmin (g, Tuscaloosa, Ala.)
Colbert County (ground water)
H. B. Harris (g, Tuscaloosa, Ala.)
Escambia County (ground water)
J. W. Cagle (g, Tuscaloosa, Ala.)
Etowah County (ground water)
L. V. Causey (g, Tuscaloosa, Ala.)
Franklin County (ground water)
R. R. Peace (g, Tuscaloosa, Ala.)
Hale County (ground water)
Q. F. Paulson (g, Tuscaloosa, Ala.)
Lauderdale County (ground water)
H. B. Harris (g, Tuscaloosa, Ala.)
Limestone County (ground water)
W. M. McMaster (g, Tuscaloosa, Ala.)
Lawrence County (ground water)
W. F. Harris (g, Tuscaloosa, Ala.)
Marshall County (ground water)
T. H. Sanford (g, Tuscaloosa, Ala.)
Morgan County (ground water)
C. L. Dodson (g, Tuscaloosa, Ala.)
Pickens County (ground water)
J. G. Newton (g, Tuscaloosa, Ala.)
Russell County (ground water)
J. C. Scott (g, Tuscaloosa, Ala.)
St. Clair County (ground water)
L. V. Causey (g, Tuscaloosa, Ala.)
Tuscaloosa County (ground water)
Q. F. Paulson (g, Tuscaloosa, Ala.)
Athens and vicinity (ground water)
W. M. McMaster (g, Tuscaloosa, Ala.)
Elkmont quadrangle, Limestone County (geology)
W. M. McMaster (g, Tuscaloosa, Ala.)
Huntsville and Madison County (ground water)
T. H. Sanford (g, Tuscaloosa, Ala.)
Russellville and vicinity (ground water)
R. R. Peace (g, Tuscaloosa, Ala.)
Salem quadrangle, Limestone County (geology)
W. M. McMaster (g. Tuscaloosa, Ala.)
Sylacauga area (ground water)
G. W. Swindel (g, Tuscaloosa, Ala.)

Alaska:
General geology:
Index of literature on Alaskan geology
E. H. Cobb (M)
Geologic map
G. O. Gates (M)
Tectonic map
G. Gryc (W)
Glacial map
D. M. Hopkins (M)

Alaska—Continued
General geology—Continued
Landform map
H. W. Coulter (W)
Physiographic divisions
C. Wahrhaftig (M)
Rock-types map
L. A. Vehle (W)
Engineering soils map
T. N. V. Karlstrom (W)
Climatic map
A. T. Fernald (W)
Vegetation map
L. A. Spetzman (W)
Compilation of geologic maps, 1:250,000 quadrangles
W. H. Condon (M)
Mesozoic stratigraphy
W. W. Patton and A. Grantz (M)
Cenozoic mollusks
F. S. MacNeil (M)
**Central and northern Alaska Cenozoic
D. M. Hopkins (M)
Aleutian Trench–Trinity Island
G. W. Moore (M)
*Eastern Aleutian Islands
R. E. Wilcox (D)
*Western Aleutian Islands
R. E. Wilcox (D)
**Buckland and Huslia Rivers area, west-central Alaska
W. W. Patton, Jr. (M)
**Charley River quadrangle
E. E. Brabb (M)
**Delong Mountains and Point Hope quadrangles
I. L. Tailleur (M)
**Fairbanks quadrangle
F. R. Weber (College, Alaska)
*Petrology and volcanism, Katmai National Monument
G. H. Curtis (M)
**Iliamna quadrangle
R. L. Detterman (M)
**Livengood quadrangle
B. Taber (M)
*Mount Michelson area
E. G. Sable (Elizabethtown, Ky.)
Cretaceous Foraminifera of the Nelchina area
H. R. Bergquist (W)
**Shungnak-Hughes area
W. W. Patton, Jr. (M)
*Windy-Curry area
R. Kachadoorian (M)
*Southern Wrangell Mountains
E. M. MacKevett, Jr. (M)
**Lower Yukon–Norton Sound region
J. M. Hoare (M)
Mineral resources:
Metallogenic provinces
C. L. Sainsbury (M)
Geochemical prospecting techniques
R. M. Chapman (D)
**Regional geology and mineral resources, southeastern Alaska
R. A. Loney (M)
Uranium-thorium reconnaissance
E. M. MacKevett, Jr. (M)

Alaska—Continued
Mineral resources—Continued
**Klukwan iron district
E. C. Robertson (W)
Quicksilver deposits, southwestern Alaska
E. M. MacKevett, Jr. (M)
**Southern Brooks Range (copper, precious metals)
W. P. Brosgé (M)
*Nome C–1 and D–1 quadrangles (gold)
C. L. Hummel (Bangkok, Thailand)
*Tofty placer district (gold, tin)
D. M. Hopkins (M)
Seward Peninsula tin investigations
P. L. Killeen (W)
*Lost River mining district (tin and beryllium)
C. L. Sainsbury (M)
*Heceta-Tuxekan area (high-calcium limestone)
G. D. Eberlein (M)
*Gulf of Alaska Tertiary province (petroleum)
G. Plafker (M)
**Northern Alaska petroleum investigations
G. Gryc (W)
*Iniskin-Tuxedni region
R. L. Detterman (M)
**Nelchina area (petroleum)
A. Grantz (M)
**Lower Yukon-Koyukuk area (petroleum)
W. W. Patton, Jr. (M)
*Beluga-Yentna area (coal)
F. F. Barnes (M)
*Matanuska coal field
F. F. Barnes (M)
Matanuska stratigraphic studies (coal)
A. Grantz (M)
*Nenana coal investigations
C. Wahrhaftig (M)
Engineering geology and permafrost:
*Surficial and engineering geology studies and construction materials sources
T. L. Péwé (College, Alaska)
Origin and stratigraphy of ground ice in central Alaska
T. L. Péwé (College, Alaska)
*Surficial geology of the Anchorage-Matanuska Glacier area (construction-site planning)
T. N. V. Karlstrom (W)
*Surficial geology of the Barter Island–Mt. Chamberlin area
C. R. Lewis (W)
Surficial geology of the Bristol Bay area (construction-site planning)
H. R. Schmoll (W)
*Nuclear test-site evaluation, Chariot
G. D. Eberlein (M)
*Surficial geology of the lower Chitina Valley (construction-site planning)
L. A. Yehle (W)
*Surficial geology of the northeastern Copper River (construction-site planning)
O. J. Ferrians, Jr. (Glennallen, Alaska)
*Surficial geology of the southeastern Copper River (construction-site planning)
D. R. Nichols (W)
*Surficial geology of the southwestern Copper River basin (construction-site planning)
J. R. Williams (W)

Alaska—Continued
Engineering geology and permafrost—Continued
*Surficial geology of the eastern Denali Highway (construction-site planning)
D. R. Nichols (W)
*Surficial geology of the Johnson River district (construction-site planning)
H. L. Foster (W)
**Surficial geology of the Kenai lowland (construction-site planning)
T. N. V. Karlstrom (W)
**Kobuk River valley (construction-site planning)
A. T. Fernald (W)
*Mt. Hayes D-3 and D-4 quadrangles (construction-site planning)
T. L. Péwé (College, Alaska)
*Surficial geology of the Seward-Portage Railroad (construction-site planning)
T. N. V. Karlstrom (W)
Surficial geology of the Stiese Highway area (construction-site planning)
W. E. Davies (W)
*Surficial geology of the Upper Tanana River (construction-site planning)
A. T. Fernald (W)
Surficial geology of the Taylor Highway area (construction-site planning)
H. L. Foster (W)
*Surficial geology of the Valdez-Tiekel belt (construction-site planning
H. W. Coulter (W)
Surficial geology of Yukon Flats area (construction-site planning)
T. N. V. Karlstrom (W)
**Engineering geology of Yukon-Koyukuk lowland
F. R. Weber (College, Alaska)
Geophysical studies:
Aeromagnetic surveys
D. F. Barnes (M)
Regional gravity surveys
D. F. Barnes (M)
Aerial radiological monitoring surveys, Chariot site
R. G. Bates (W)
Water resources:
General inventory of ground water
R. M. Waller (g, Anchorage, Alaska)
Relationship of permafrost to ground water
J. R. Wililams (g, Anchorage, Alaska)
Water-supply investigations for U.S. Air Force
A. J. Feulner (g, Anchorage, Alaska)
Anchorage area (ground water)
D. J. Cederstrom (g, W)
Water utilization at Anchorage
R. M. Waller (g, Anchorage, Alaska)
Project Chariot (ground water)
R. M. Waller (g, Anchorage, Alaska)
Chugiak area (ground water)
R. M. Waller (g, Anchorage, Alaska)
Cordova area (ground water)
R. M. Waller (g, Anchorage, Alaska)
Fairbanks area (ground water)
D. J. Cederstrom (g, W)
Homer area (ground water)
R. M. Waller (g, Anchorage, Alaska)

Arizona:
General geology:
Diatremes, Navajo and Hopi Indian Reservations
E. M. Shoemaker (M)
Terrestrial impact structures, Meteor Crater
E. M. Shoemaker (M)
Devonian rocks and paleogeography of central Arizona
C. Teichert (D)
Devonian rocks of northwestern Arizona
C. Teichert (D)
Stratigraphy of the Redwall limestone
E. D. McKee (D)
History of Supai-Hermit formations
E. D. McKee (D)
*Cibecue-Grasshopper area
T. L. Finnell (D)
*Southern Cochise County
P. T. Hayes (D)
*Elgin quadrangle
R. B. Raup (D)
*Upper Gila River basin, Arizona-New Mexico
R. B. Morrison (D)
*Heber quadrangle
E. J. McKay (D)
*Holy Joe Peak quadrangle
M. H. Krieger (M)
*Mount Wrightson quadrangle
H. Drewes (D)
*Show Low quadrangle
E. J. McKay (D)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Safford Valley geophysical studies
G. E. Andreason (W)
Mineral resources:
Geochemical halos of mineral deposits
L. C. Huff (D)
*McFadden Peak and Blue House Mountain quadrangles (asbestos)
A. F. Shride (D)
*Christmas quadrangle (copper, iron)
C. R. Willden (M)
*Bradshaw Mountains (copper)
C. A. Anderson (W)
*Globe-Miami area (copper)
D. W. Peterson (M)
*Klondyke quadrangle (copper)
F. S. Simons (D)
*Contact-metamorphic deposits of the Little Dragoons area (copper)
J. R. Cooper (D)
*Mammoth and Benson quadrangles (copper)
S. C. Creasey (M)
*Prescott-Paulden area (copper)
M. H. Kreiger (M)
*Twin Buttes area (copper)
J. R. Cooper (D)
*Lochiel and Nogales quadrangles (lead, zinc, copper)
F. S. Simons (D)
*Fuels potential of the Navajo Reservation, Arizona and Utah
R. B. O'Sullivan (D)

Arizona—Continued
Mineral resources—Continued
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
Lithologic studies, Colorado Plateau
R. A. Cadigan (D)
Clay studies, Colorado Plateau
L. G. Schultz (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (M)
San Rafael Group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (W)
Studies of uranium deposits
H. C. Granger (D)
*Carrizo Mountains area, Arizona-New Mexico (uranium)
J. D. Strobell (D)
Relative concentrations of chemical elements in rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Uranium deposits of the Dripping Spring Quartzite of southeastern Arizona
H. C. Granger (D)
Water resources:
The geohydrologic environment as related to water utilization in arid lands
E. S. Davidson (g, Tucson, Ariz.)
Lower Colorado River Basin hydrology
C. C. McDonald (g, Yuma, Ariz.)
Evapotranspiration theory and measurement
O. E. Leppanen (h, Phoenix, Ariz.)
Use of water by saltcedar in evapotranspirometer compared with energy budget and mass transfer computation (Buckeye)
T. E. A. Van Hylckama (h, Phoenix, Ariz.)
Effect of removing riparian vegetation, Cottonwood Wash (water)
J. E. Bowie (s, Tucson Ariz.)
Piping, an erosional phenomenon in certain silty soils of arid and semi-arid regions
G. G. Parker, R. C. Miller, and I. S. McQueen (h, D)
Flood investigations, Maricopa County
J. E. Bowie (s, Tucson, Ariz.)
Sycamore Creek basin (water)
A. Wilson (s, Tucson, Ariz.)
Study of channel flood-plain aggradation of Tusayan Washes
R. F. Hadley (h, D)
Central Apache County (ground water)
J. P. Akers (g, Tucson, Ariz.)
Northwestern Pinal County (ground water)
W. F. Hardt (g, Tucson, Ariz.)
Big Sandy valley (ground water)
W. Kam (g, Tucson, Ariz.)
Flagstaff area (ground water)
J. P. Akers (g, Tucson, Ariz.)

Arizona—Continued
Water resources—Continued
Fort Huachuca (ground water)
H. G. Page (g, Tucson, Ariz.)
Luke Air Force Base (ground water)
J. M. Cahill (g, Tucson, Ariz.)
Navajo Indian Reservation (ground water)
M. E. Cooley (g, Tucson, Ariz.)
Papago Indian Reservation (ground water)
L. A. Heindl (g, W)
Rainbow Valley—Waterman Wash (ground water)
F. R. Twenter (g, Tucson, Ariz.)
Deep aquifers in the Salt River valley
D. G. Metzger (g, Tucson, Ariz.)
San Simon basin (ground water)
N. D. White (g, Tucson, Ariz.)
Verde Valley (ground water)
D. G. Metzger (g, Tucson, Ariz.)
Willcox basin (ground water)
S. G. Brown (g, Tucson, Ariz.)

Arkansas:
Aeromagnetic interpretation, Wichita Mountains system
A. Griscom (W)
Aeromagnetic prospecting for bauxite
A. Jesperson (W)
Barite deposits
D. A. Brobst (D)
*Arkansas Basin (coal)
B. R. Haley (D)
*Ft. Smith district, Arkansas and Oklahoma (coal and gas)
T. A. Hendricks (D)
*Northern Arkansas oil and gas investigations
E. E. Glick (D)
Magnet Cove niobium investigations
L. V. Blade (Paducah, Ky.)
Artificial recharge of aquifers
R. T. Sniegocki (g, Little Rock, Ark.)
Flood investigations
R. C. Christensen (s, Fort Smith, Ark.)
Low-flow frequency studies
J. L. Patterson (s, Fort Smith, Ark.)
Arkansas River valley (ground water)
M. S. Bedinger (g, Little Rock, Ark.)
Arkansas River valley reconnaissance (ground water)
R. M. Cordova (g, Little Rock, Ark.)
Bradley, Calhoun, and Ouachita Counties (ground water)
D. R. Albin (g, Little Rock, Ark.)
Crittenden County (ground water)
R. O. Plebuch (g, Little Rock, Ark.)
Artificial recharge, Grand Prairie region (ground water)
R. T. Sniegocki (g, Little Rock Ark.)
Pea Ridge Military Park (ground water)
R. O. Plebuch (g, Little Rock, Ark.)
Ouachita Mountains (ground water)
R. M. Cordova (g, Little Rock, Ark.)
Ground water along U.S. Highway 70 from Pulaski County to Crittenden County
H. N. Halberg (g, Little Rock, Ark.)
Reconnaissance study of quality of water in Smackover Creek
J. P. Reer (q, Fayetteville, Ark.)
Surface-water resources of the White River basin, 1948–59
J. W. Hubble (q, Fayetteville, Ark.)

California:
General geology:
Cenozoic Foraminifera of California
P. J. Smith (M)
Foraminifera of the Lodo Formation
M. C. Israelsky (M)
*San Andreas fault
L. F. Noble (Valyermo, Calif.)
Glacial geology of the west-central Sierra Nevada region
F. M. Fryxell (Rock Island, Ill.)
*South-central Mojave Desert
T. W. Dibblee, Jr. (M)
*California Coast Range ultramafic rocks
E. H. Bailey (M)
Glaucophane schist terranes within the Franciscan Formation
R. G. Coleman (M)
*Ash Meadows quadrangle, California and Nevada
C. S. Denny (W)
*Big Maria Mountains quadrangle
W. B. Hamilton (D)
*Blanco Mountain quadrangle
C. A. Nelson (Los Angeles, Calif.)
*Petrology of the Burney area
G. A. MacDonald (Honolulu, Hawaii)
*Condrey Mountain quadrangle
P. E. Hotz (M)
Geology and paleontology of the Cuyama Valley area
G. Vedder (M)
*Death Valley
C. B. Hunt (Baltimore, Md.)
*Funeral Peak quadrangle
H. D. Drewes (D)
*Independence quadrangle
D. C. Ross (M)
*Merced Peak quadrangle
D. L. Peck (M)
*Mt. Pinchot quadrangle
J. G. Moore (M)
*Northwest Sacramento Valley (petroleum)
R. D. Brown, Jr. (M)
*Salinas Valley
D. L. Durham (M)
*San Nicolas Island
J. G. Vedder (M)
*Shuteye Peak area
N. K. Huber (M)
Structural geology of the Sierra foothills mineral belt (copper, zinc, gold, chromite)
L. D. Clark (M)
*Weaverville, French Gulch, and Hayfork quadrangles, southern Klamath Mountains
W. P. Irwin (M)
Mineral resources:
Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
W. C. Smith (M)
*Furnace Creek area (boron)
J. F. McAllister (M)
*Western Mojave Desert (boron)
T. W. Dibblee, Jr. (M)
*Geology and origin of the saline deposits of Searles Lake (boron)
G. I. Smith (M)

California—Continued
Mineral resources—Continued
Chromite deposits of northern California
F. G. Wells (W)
*Panamint Butte quadrangle, including special geochemical studies (lead-silver)
W. E. Hall (W)
*New York Butte quadrangle (lead-zinc)
W. C. Smith (M)
Lateritic nickel deposits of the Klamath Mountains, Oregon-California
P. E. Hotz (M)
*Eastern Los Angeles basin (petroleum)
J. E. Schoellhamer (W)
*Mt. Diablo area (quicksilver, copper, gold, silver)
E. H. Pampeyan (M)
*Bishop tungsten district
P. C. Bateman (M)
*Geologic study of the Sierra Nevada batholith (tungsten, gold, base metals)
P. C. Bateman (M)
*Eastern Sierra tungsten area: Devil's Postpile quadrangle (tungsten, base metals)
N. K. Huber (M)
Western oxidized-zinc deposits
A. V. Heyl (W)
Engineering geology:
*Surficial geology of the Beverly Hills, Venice, and Topanga quadrangles, Los Angeles (urban geology)
J. T. McGill (Los Angeles, Calif.)
*Malibu Beach quadrangle (urban geology)
R. F. Yerkes (M)
*Oakland East quadrangle (urban geology)
D. H. Radbruch (M)
*Point Dume quadrangle (urban geology)
J. E. Schoellhamer (W)
*San Francisco Bay area, San Francisco North quadrangle (urban geology)
J. Schlocker (M)
*San Francisco Bay area, San Francisco South quadrangle (urban geology)
M. G. Bonilla (M)
*San Mateo quadrangle (urban geology)
G. O. Gates (M)
Geophysical studies:
Rocks and structures of the Los Angeles basin, and their gravitational effects
T. H. McCulloh (Riverside, Calif.)
Aerial radiological monitoring surveys, Los Angeles
K. G. Brooks (W)
Sacramento Valley and Coast Range geophysical studies
G. D. Bath (M)
Geophysical studies, San Francisco Bay area
G. D. Bath (M)
Aerial radiological monitoring surveys, San Francisco
J. A. Pitkin (W)
Sierra Nevada geophysical studies
H. W. Oliver (M)
Water resources:
Lower Colorado River Basin hydrology
C. C. McDonald (g, Yuma, Ariz.)
Agricultural Research Service soil-moisture study
R. E. Evenson (g, Sacramento, Calif.)

California—Continued
Water resources—Continued
Springs of California
Robert Brennan (q, Sacramento, Calif.)
Water-loss and water-gain studies in California
W. C. Peterson (s, M)
Floods from small areas in California
L. E. Young (s, M)
Natural water loss, southern California
W. Hofmann (s, M)
North Pacific coast area (surface water)
W. Hofmann (s, M)
Occurrence and distribution of minor elements in fresh and saline waters of California
W. D. Silvey (q, Sacramento, Calif.)
Solute composition and minor-element distribution in lacustrine closed basins
B. F. Jones (q, W)
Solute-solid relations in lacustrine closed basins of the alkali-carbonate type
B. F. Jones (q, W)
Clastic sedimentation in a bolson environment
L. K. Lustig (q, Boston, Mass.)
Cache Creek sediment investigation
George Porterfield (q, Sacramento, Calif.)
Stony Gorge Reservoir sedimentation survey
C. A. Dunnam (q, Sacramento, Calif.)
Snowmelt hydrology of a Sierra Nevada stream
W. Hofmann (s, M)
Flood inundation, Lower Eel River
W. Hofmann (s, M)
Camp Pendleton Marine Corps Base (ground water)
J. S. Bader (g, Sacramento, Calif.)
Death Valley National Monument (ground water)
F. Kunkel (g, Sacramento, Calif.)
Edwards Air Force Base (ground water)
W. R. Moyle (g, Sacramento, Calif.)
Inyokern Naval Ordnance Test Station (ground water)
F. Kunkel (g, Sacramento, Calif.)
Lower Mojave area, west part (ground water)
G. M. Hogenson (g, Sacramento, Calif.)
Dale Lake area (ground water)
G. M. Hogenson (g, Sacramento, Calif.)
Ducor-Famoso area (ground water)
G. S. Hilton (g, Sacramento, Calif.)
Furnace Creek and Pinto Basin (ground water)
G. M. Hogenson (g, Sacramento, Calif.)
Kaweah-Tule area (ground water)
M. G. Croft (g, Sacramento, Calif.)
Kern River fan (ground water)
R. H. Dale (g, Sacramento, Calif.)
Livermore Valley investigation (Alameda Creek basin) (water resources)
R. T. Kiser (q, Sacramento, Calif.)
Lompoc Plain (ground water)
R. E. Evenson (g, Santa Barbara, Calif.)
Oak Mountain Air Force Facility (ground water)
G. A. Miller (g, Sacramento, Calif.)
Point Arguello (ground water)
R. E. Evenson (g, Sacramento, Calif.)
Point Mugu area (ground water)
R. W. Page (g, Sacramento, Calif.)
San Antonio Valley (ground water)
R. E. Evenson (g, Sacramento, Calif.)

California—Continued
Water resources—Continued
San Francisco Bay barriers (ground water)
G. M. Hogenson (g, Sacramento, Calif.)
San Nicholas Island (ground water)
R. W. Page (g, Sacramento, Calif.)
Santa Barbara County (ground water)
R. E. Evenson (g, Sacramento, Calif.)
Reservoir evaporation, San Diego County
W. Hofmann (s, M)
Santa Maria Valley (ground water)
R. E. Evenson (g, Sacramento, Calif.)
Sierra Ordnance Depot (ground water)
G. S. Hilton (g, Sacramento, Calif.)
South coast basins (ground water)
R. E. Evenson (g, Sacramento, Calif.)
A study of some effects of diversion works on the Trinity River
George Porterfield (q, Sacramento)
Twentynine Palms Marine Corps Training Center (ground water)
H. B. Dyer (g, Sacramento, Calif.)

Colorado:
General geology:
Upper Cretaceous stratigraphy, northwestern Colorado and northeastern Utah
A. D. Zapp (D)
Tuffs of the Green River Formation
R. L. Griggs (D)
Investigation of Jurassic stratigraphy, south-central Wyoming and northwestern Colorado
G. N. Pipiringos (D)
Pennsylvanian and Permian stratigraphy, Front Range
E. K. Maughn (D)
Stratigraphy and paleontology of the Pierre Shale, Front Range area, Colorado and Wyoming
W. A. Cobban and G. R. Scott (D)
Lithologic studies, Colorado Plateau
R. A. Cadigan (D)
Clay studies, Colorado Plateau
L. G. Schultz (D)
*Berthoud Pass quadrangle
P. K. Theobald (D)
*Bottle Pass quadrangle
R. B. Taylor (D)
Petrology and geochemistry of the Boulder Creek batholith, Colorado Front Range
G. Phair (W)
*Boulder quadrangle
R. F. Wilson and C. T. Wrucke (D)
*Cameron Mountain quadrangle
M. G. Dings (D)
*Central City quadrangle
P. K. Sims (Minneapolis, Minn.)
*Eldorado Springs quadrangle
J. D. Wells (D)
*Empire quadrangle
W. A. Braddock (D)
*Glenwood Springs quadrangle
N. W. Bass (D)
*Precambrian rocks in Idaho Springs area
R. H. Moench (D)

Colorado—Continued
General geology—Continued
Petrology and geochemistry of the Laramide intrusives in the Colorado Front Range
G. Phair (W)
*Mountain front area, east-central Front Range
D. M. Sheridan (D)
*Squaw Pass quadrangle
D. M. Sheridan (D)
Distribution of elements in Mount Princeton area
P. Toulmin (W)
*Upper South Platte River, North Fork
G. R. Scott (D)
Colorado National Monument (general geology)
S. W. Lohman (g, D)
Mineral resources:
*Lake George district (beryllium)
C. C. Hawley (D)
*Poncha Springs and Bonanza quadrangles (fluorspar)
R. E. Van Alstine (W)
Western oxidized zinc deposits
A. V. Heyl (W)
*Central City-Georgetown area, including studies of the Precambrian history of the Front Range (base, precious, and radioactive metals)
P. K. Sims (Minneapolis, Minn.)
*Volcanic and economic geology of the Creede caldera (base and precious metals, fluorspar)
T. A. Steven (D)
*Holy Cross quadrangle and the Colorado mineral belt (lead, zinc, silver, copper, gold)
O. Tweto (D)
*Minturn quadrangle (zinc, silver, copper, lead, gold)
T. S. Lovering (D)
*Rico district (lead, zinc, silver)
E. T. McKnight (W)
*San Juan mining area, including detailed study of the Silverton Caldera (lead, zinc, silver, gold, copper)
R. G. Luedke (W)
*Tenmile Range, including the Kokomo mining district (base and precious metals)
A. H. Koschmann (D)
*Powderhorn area, Gunnison County (thorium)
J. C. Olson (D)
*Wet Mountains (thorium, base and precious metals)
M. R. Brock (D)
Wallrock alteration and its relation to thorium deposition in the Wet Mountains
G. Phair (W)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. I. Fischer (D)
Relative concentrations of chemical elements in rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (M)

Colorado—Continued
Mineral resources—Continued
San Rafael Group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (W)
*Baggs area, Wyoming and Colorado (uranium)
G. E. Prichard (D)
*Bull Canyon district (vanadium, uranium)
C. H. Roach (D)
Exploration for uranium deposits in the Gypsum Valley district
C. F. Withington (W)
*La Sal area, Utah-Colorado (uranium, vanadium)
W. D. Carter (Santiago, Chile)
*Lisbon Valley area, Utah-Colorado (uranium, vanadium, copper)
G. W. Weir (Berea, Ky.)
*Maybell-Lay area, Moffat County (uranium)
M. J. Bergin (W)
*Ralston Buttes (Uranium)
D. M. Sheridan (D)
*Western San Juan Mountains (uranium, vanadium, gold)
A. L. Bush (W)
*Slick Rock district (uranium, vanadium)
D. R. Shawe (D)
Uravan district (vanadium, uranium)
R. L. Boardman (W)
*Ute Mountains (uranium, vanadium)
E. B. Ekren (D)
*Animas River area, Colorado and New Mexico (coal, oil, and gas)
H. Barnes (D)
*Carbondale coal field
J. R. Donnell (D)
*Eastern North Park (coal, oil, and gas)
D. M. Kinney (W)
*Western North Park (coal, oil, and gas)
W. J. Hail (D)
*Trinidad coal field
R. B. Johnson (D)
*Oil shale investigations
D. C. Duncan (W)
*Grand-Battlement Mesa oil shale
J. R. Donnell (D)
Engineering geology and geophysical studies:
*Air Force Academy (construction-site planning)
D. J. Varnes (D)
Black Canyon of the Gunnison River (construction-site planning)
W. R. Hansen (D)
*Upper Green River valley (construction-site planning)
W. R. Hansen (D)
*Denver metropolitan area (urban geology)
R. M. Lindvall (D)
*Golden quadrangle (urban geology)
R. Van Horn (D)
*Morrison quadrangle (urban geology)
J. H. Smith (D)
*Pueblo and vicinity (urban geology)
G. R. Scott (D)
Engineering geology of the Roberts Tunnel
C. S. Robinson (D)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)

Colorado—Continued
Engineering geology and geophysical studies—Continued
Aerial radiological monitoring surveys, Rocky Flats
J. A. MacKallor (W)
Water resources:
Occurrence and development of ground water in Colorado
J. A. McConaghy (g, D)
Characteristics of municipal water supplies in Colorado
E. A. Moulder (g, D)
Use of plant species or communities as indicators of soil-moisture availability
F. A. Branson (h, D)
Study of the mechanics of hillslope erosion
S. A. Schumm (h, D)
Effects of sediment characteristics on fluvial morphology hydraulics
S. A. Schumm (h, D)
Effects of grazing exclusion in Badger Wash area
G. C. Lusby (h, D)
Bent County (ground water)
J. H. Irwin (g, D)
Ogallala Formation, eastern Cheyenne and Kiowa Counties (ground water)
A. J. Boettcher (g, D)
Huerfano County (ground water)
T. G. McLaughlin (g, D)
Kit Carson County (ground water)
G. H. Chase (g, D)
Otero County and part of Crowley County (ground water)
W. G. Weist (g, D)
Prowers County (ground water)
P. T. Voegel (g, D)
Pueblo and Fremont Counties (ground water)
H. E. McGovern (g, D)
Washington County (ground water)
H. E. McGovern (g, D)
Yuma County (ground water)
W. G. Weist (g, D)
Hydrology of Arkansas River basin—Canon City to State line
C. T. Jenkins (g, D)
Arkansas River basin (surface water)
C. T. Jenkins (s, D)
Big Sandy valley below Limon (ground water)
D. L. Coffin (g, D)
Cache La Poudre valley (ground water)
L. A. Hershey (g, D)
Denver Basin (ground water)
G. H. Chase (g, D)
Fountain and Jimmy Camp Valleys (ground water)
E. D. Jenkins (g, D)
Fluvial sedimentation and runoff in Kiowa Creek
J. C. Mundorff (q, Lincoln, Nebr.)
Investigation of trap efficiencies of K–79 Reservoir, Kiowa Creek basin
J. C. Mundorff (q, Lincoln, Nebr.)
North and Middle Parks (ground water)
P. T. Voegel (g, D)
Rocky Mountain Arsenal (ground water)
M. C. Van Lewen (g, D)
Ute Mountain–Ute Indian Reservation (ground water)
J. H. Irwin (g. D)

Connecticut:
General geology:
*Stratigraphy and structure of Taconic rocks
E-an Zen (W)
*Ansonia, Mount Carmel, and Southington quadrangles; bedrock geologic mapping
C. E. Fritts (D)
*Ashley Falls and Bashbish Falls quadrangles, Massachusetts and Connecticut, and Egremont quadrangle, Massachusetts; surficial geologic mapping
J. H. Hartshorn (Boston, Mass.)
*Ashaway quadrangle, Rhode Island and Connecticut; bedrock geologic mapping
T. G. Feininger (Boston, Mass.)
*Ashaway and Watch Hills quadrangles, Connecticut and Rhode Island; surficial geologic mapping
J. P. Schafer (Boston, Mass.)
*Bristol and New Britain quadrangles, bedrock geologic mapping
H. E. Simpson (D)
*Broad Brook and Manchester quadrangles
R. B. Colton (D)
*Columbia, Fitchville, Marlboro, and Willimantic quadrangles; bedrock geologic mapping
G. L. Snyder (D)
*Durham quadrangle
H. E. Simpson (D)
*Hampton, Plainfield, and Scotland quadrangles; bedrock geologic mapping
H. R. Dixon (Boston, Mass.)
*Meriden quadrangle; bedrock geologic mapping
P. M. Hanshaw (Boston, Mass.)
*Montville, Mystic, New London, Niantic, and Uncasville quadrangles; bedrock geologic mapping
R. Goldsmith (Boston, Mass.)
*Mystic, New London, and Niantic quadrangles; surficial geologic mapping
R. Goldsmith (D)
*New Hartford quadrangle
R. W. Schnabel (D)
*Southwick quadrangle, Massachusetts and Connecticut
R. W. Schnabel (D)
*Springfield South quadrangle, Massachusetts and Connecticut
J. H. Hartshorn and C. Koteff (Boston, Mass.)
*Tariffville and Windsor Locks quadrangles; bedrock geologic mapping
R. W. Schnabel (D)
*Thompson quadrangle, Connecticut and Rhode Island
P. M. Hanshaw and H. R. Dixon (Boston, Mass.)
*Voluntown quadrangle, Rhode Island and Connecticut
T. G. Feiniger (Boston, Mass.)
*Watch Hill quadrangle, Connecticut-Rhode Island; bedrock geologic mapping
G. E. Moore, Jr. (Columbus, Ohio)
*West Springfield quadrangle, Massachusetts and Connecticut
R. B. Colton (D) and J. H. Hartshorn (Boston, Mass.)
Hartford North quadrangle
R. V. Cushman (g, Middletown, Conn.)
Recognition of late glacial substages in New England and New York
J. E. Upson (g, Mineola, N.Y.)

Connecticut—Continued
Water resources:
North-central Connecticut (ground water)
R. V. Cushman (g, Middletown, Conn.)
Bristol-Plainville-Southington area (ground water)
A. M. LaSala, Jr. (g, Middletown, Conn.)
Farmington-Granby area (ground water)
A. D. Randall (g, Middletown, Conn.)
Water resources of Connecticut—Part 1, Quinebaug River basin
Chester E. Thomas, Jr. (q. Albany, N.Y.)
Water resources, Quinebaug River basin
A. D. Randall (g, Albany, N.Y.)
Lower Quinnipiac and Mill River lowlands (ground water)
A. M. LaSala, Jr. (g, Middletown, Conn.)
Tariffville quadrangle (surficial geology)
A. D. Randall (g, Middletown, Conn.)
Watch Hill quadrangle (ground water)
K. E. Johnson (g, Providence, R.I.)
Waterbury-Bristol area (ground water)
R. V. Cushman (g, Middletown, Conn.)

Delaware:
Water-table and engineering mapping
D. H. Boggess (g, Newark Del.)
Chemical quality—Natural waters of Delaware
P. W. Anderson (q, Philadelphia, Pa.)
Salinity conditions of lower Delaware River basin
D. McCartney (q, Philadephia, Pa.)
Salt-water encroachment in the Lewes-Rehoboth area
D. R. Rima (g, Newark, Del.)
New Castle County (ground water)
D. R. Rima (g, Newark, Del.)
Newark area (ground water)
D. R. Rima (g, Newark, Del.)
Red Clay Valley (ground water)
D. H. Boggess (g, Newark, Del.)

Florida:
Mesozoic rocks of Florida and eastern Gulf Coast
E. R. Applin (Jackson, Miss.)
Subsurface Paleozoic rocks of Florida
J. M. Berdan (W)
*Land-pebble phosphate deposits
J. B. Cathcart (D)
Phosphate deposits of northern Florida
G. H. Espenshade (W)
Bridge-site studies (surface water)
R. W. Pride (s, Ocala, Fla.)
Artesian water in Tertiary limestones in Florida, southern Georgia, and adjacent parts of Alabama and South Carolina
V. T. Stringfield (w, W)
Physical characteristics of selected Florida lakes
W. E. Kenner (s, Ocala, Fla.)
Mechanics of diffusion, fresh and salt water
H. H. Cooper (g, Tallahassee, Fla.)
Special studies, surface water
R. W. Pride (s, Ocala, Fla.)
Alachua, Bradford, Clay, and Union Counties (water resources)
W. E. Clark (g, Tallahassee, Fla.)
Alachua, Bradford, Clay, and Union Counties (surface water)
R. W. Pride (s, Ocala, Fla.)
Central Broward County (ground water)
H. Klein (g, Tallahassee, Fla.)

Florida—Continued
Northeastern Broward County (ground water)
G. R. Tarver (g, Tallahassee, Fla.)
Collier County (ground water)
H. J. McCoy (g, Tallahassee, Fla.)
Dade County (ground water)
H. Klein (g, Tallahassee, Fla.)
Salt-water encroachment studies in Dade County
H. Klein (g, Tallahassee, Fla.)
Area B, Dade County (ground water)
C. B. Sherwood (g, Tallahassee, Fla.)
Duval, Nassau, and Baker Counties (ground water)
Tarver, G. (g, Tallahassee, Fla.)
Glades and Hendry Counties (ground water)
W. F. Lichtler (g, Tallahassee, Fla.)
Orange County (water resources)
W. F. Lichter (g, Tallahassee, Fla.)
Polk County (ground water)
H. G. Stewart (g, Tallahassee, Fla.)
St. Johns, Flagler, and Putnam Counties (ground water)
D. W. Brown (g, Tallahassee, Fla.)
Enconfina Creek basin area (water resources)
R. H. Musgrove (s, Ocala, Fla.)
Salinity in the Miami River
S. D. Leach (s, Ocala, Fla.)
Water resources of Myakka River basin
K. A. MacKichan (q, Ocala, Fla.)
Snake Creek Canal salinity study
F. A. Kohout (g, Tallahassee, Fla.)
Snapper Creek, Snake Creek, and Levee 30 studies (ground water)
C. B. Sherwood (g, Tallahassee, Fla.)
Water resources of the Tampa Bay area
K. A. MacKichan (q, Ocala, Fla.)

Georgia:
Clinton iron ores of the southern Appalachians
R. P. Sheldon (D)
Mesozoic rocks of Florida and eastern Gulf coast
E. R. Applin (Jackson, Miss.)
Pre-Selma Cretaceous rocks of Alabama and adjacent States
L. C. Conant (Tripoli, Libya)
Aerial radiological monitoring surveys, Georgia Nuclear Aircraft Laboratory
J. A. MacKallor (W)
Aerial radiological monitoring surveys, Savannah River Plant, Georgia and South Carolina
R. G. Schmidt (W)
Artesian water in Tertiary limestones in Florida, southern Georgia, and adjacent parts of Alabama and South Carolina
V. T. Stringfield (w, W)
River-systems studies
A. N. Cameron (s, Atlanta, Ga.)
Relation of geology to low flow
O. J. Cosner (s, Atlanta, Ga.)
Low-flow studies
R. F. Carter (s, Atlanta, Ga.)
Areal flood studies
C. M. Bunch (s, Atlanta, Ga.)
Flood gaging
C. M. Bunch (s, Atlanta, Ga.)
Bridge-site investigations (surface water)
C. M. Bunch (s, Atlanta, Ga.)

Georgia—Continued
Stratigraphy of the Trent marl and related units
P. M. Brown (g, Raleigh, N.C.)
Solution subsidence of a limestone terrane in southwest Georgia
S. M. Herrick (g, Atlanta, Ga.)
Paleozoic rock area, Bartow County
M. G. Croft (g, Atlanta, Ga.)
Paleozoic rock area, Chattooga County (ground water)
C. W. Cressler (g, Atlanta Ga.)
Floyd County (ground water)
H. B. Counts (g, Atlanta, Ga.)
Lee and Sumter Counties (ground water)
V. Owen (g, Atlanta, Ga.)
Mitchell County (ground water)
V. Owen (g, Atlanta, Ga.)
Seminole, Decatur, and Grady Counties (ground water)
V. Owen (g, Atlanta, Ga.)
Paleozoic rock area, Walker County (ground water)
C. W. Cressler (g, Atlanta, Ga.)
Salt-water encroachment in the Brunswick area
R. L. Wait (g, Atlanta, Ga.)
Georgia Nuclear Laboratory area (ground water)
J. W. Stewart (g, Atlanta, Ga.)
Macon area (ground water)
H. E. LeGrand (w, W)
Salt-water encroachment in the Savannah area
H. B. Counts (g, Atlanta, Ga.)

Hawaii:
Geological, geochemical, and geophysical studies of Hawaiian volcanology
D. H. Richter (Hawaii)
High-alumina weathered basalt on Kauai, Hawaii
S. H. Patterson (W)
Hydrologic studies
G. T. Hirashima (s, Honolulu, Hawaii)
Effects of land and water use on ground water
F. N. Visher (g, Honolulu, Hawaii)
Flood gaging, Oahu
E. Pearson (s, Honolulu, Hawaii)
Central and southern Oahu (ground water)
F. N. Visher (g, Honolulu, Hawaii)
Mokuleia-Waialua area, Oahu (ground water)
D. A. Davis (g, Honolulu, Hawaii)
Waianae district, Oahu (ground water)
F. N. Visher (g, Honolulu, Hawaii)
Windward Oahu (ground water)
K. J. Takasaki (g, Honolulu, Hawaii)

Idaho:
General geology:
**South-central Idaho
C. P. Ross (D)
*Bancroft quadrangle
S. S. Oriel (D)
*Geochemistry and metamorphism of the Belt Series, Clark Fork and Packsaddle Mountain quadrangles, Idaho and Montana
J. E. Harrison (D)
*Big Creek quadrangle
B. F. Leonard (D)
*Doublesprings quadrangle
W. J. Mapel (D)
*Jarbidge area, Nevada and Idaho
R. R. Coats (M)

Idaho—Continued
General geology—Continued
*Leadore and Patterson quadrangles
E. T. Ruppel (D)
**Mackay quadrangle
C. P. Ross (D)
*Morrisson Lake quadrangle, Montana and Idaho
E. T. Cressman (Lexington, Ky.)
*Metamorphism of the Orofino area
A. Hietanen-Makela (M)
*Owyhee and Mt. City quadrangles, Nevada-Idaho
R. R. Coats (M)
*Riggins quadrangle
W. B. Hamilton (D)
**Regional geology and structure of the central Snake River plain
H. A. Powers (D)
*Snake River valley, American Falls region
D. E. Trimble (D)
*Snake River valley, western region
H. A. Powers (D)
Petrology of volcanic rocks, Snake River valley
H. A. Powers (D)
**Geologic mapping of the Spokane-Wallace region, Washington-Idaho
A. B. Griggs (M)
*Yellow Pine quadrangle
B. F. Leonard (D)
Mineral resources:
*Greenacres quadrangle, Washington-Idaho (high-alumina clays)
P. L. Weis (Spokane, Wash.)
*Blackbird Mountain area (cobalt)
J. S. Vhay (Spokane, Wash.)
*Coeud d'Alene mining district (lead, zinc, silver)
S. W. Hobbs (W)
*Thunder Mountain niobium area, Montana-Idaho
R. L. Parker (D)
*Aspen Range–Dry Ridge area (phosphate)
V. E. McKelvey (W)
*Soda Springs quadrangle, including studies of the Bannock thrust zone (phosphate)
F. C. Armstrong (Spokane, Wash.)
*Radioactive placer deposits of central Idaho
D. L. Schmidt (D)
*Mt. Spokane quadrangle, Washington and Idaho (uranium)
A. E. Wiessenborn (Spokane, Wash.)
Geophysical studies:
Pacific Northwest geophysical studies
W. E. Davis (M)
Aerial radiological monitoring surveys, National Reactor Testing Station
R. G. Bates (W)
Water resources:
Flood investigations
S. O. Decker (s, Boise, Idaho)
Aberdeen-Springfield area (ground water)
H. G. Sisco (g, Boise, Idaho)
American Falls (ground water)
M. J. Mundorff (g, Boise, Idaho)
Artesian City area (ground water)
E. G. Corsthwaite (g, Boise, Idaho)
Challis area (ground water)
M. J. Mundorff (g, Boise, Idaho)

Idaho—Continued
Water resources—Continued
Little Lost River basin (water resources)
M. J. Mundorff (g, Boise, Idaho)
Michaud Flats (ground water)
E. G. Crosthwaite (g, Boise, Idaho)
Mud Lake Basin (ground water)
P. R. Stevens (g, Boise, Idaho)
Geology, hydrology, and waste disposal at the National Reactor Testing Station
R. L. Nace (w, W)
Hydrology of subsurface waste disposal, National Reactor Testing Station
P. H. Jones (g, Boise, Idaho)
Research on hydrology, National Reactor Testing Station
E. H. Walker (g, Boise, Idaho)
Unsaturated flow, National Reactor Testing Station
P. H. Jones (g, Boise, Idaho)
Teton Basin (ground water)
M. J. Mundorff (g, Boise, Idaho)
Salmon Falls Creek area (ground water)
E. G. Crosthwaite (g, Boise, Idaho)
Sand Point area (ground water)
E. H. Walker (g, Boise, Idaho)
Spokane River valley (ground water)
M. J. Mundorff (g, Boise, Idaho)
Feasibility of artificial recharge of the Snake Plain aquifer
M. J. Mundorff (g, Boise, Idaho)
Upper Star Valley (ground water)
M. J. Mundorff (g, Boise, Idaho)
Lower Teton Basin (ground water)
E. G. Crosthwaite (g, Boise, Idaho)
Upper Weiser basin (ground water)
M. J. Mundorff (g, Boise, Idaho)

Illinois:
Aerial radiological monitoring surveys, Chicago
G. M. Flint, Jr. (W)
Geologic development of the Ohio River valley
L. L. Ray (W)
*Stratigraphy of the lead-zinc district near Dubuque
J. W. Whitlow (W)
*Wisconsin zinc-lead mining district
J. W. Whitlow (W)
Low-flow frequency analyses
W. D. Mitchell (s, Champaign, Ill.)
Low-flow partial-record investigation
D. W. Ellis (s, Champaign, Ill.)
Floods from small areas
W. D. Mitchell (s, Champaign, Ill.)
Bridge-site studies (surface water)
W. D. Mitchell (s, Champaign, Ill.)
Northeastern Illinois inundation mapping
W. D. Mitchell (s, Champaign, Ill.)

Indiana:
Geologic development of the Ohio River valley
L. L. Ray (W)
*Quaternary geology of the Owensboro quadrangle, Kentucky and Indiana
L. L. Ray (W)
Lake mapping and stabilization (surface water)
D. C. Perkins (s, Indianapolis, Ind.)
Low-flow characteristics
R. E. Hoggatt (s, Indianapolis, Ind.)

Indiana—Continued
Northwestern Indiana (ground water)
J. S. Rosenshein (g, Indianapolis, Ind.)
Southeastern Indiana (ground water)
J. S. Rosenshein (g, Indianapolis, Ind.)
West-central Indiana (ground water)
F. A. Watkins (g, Indianapolis, Ind.)
Adams County (ground water)
F. A. Watkins (g, Indianapolis, Ind.)
Clay, Greene, Owen, Sullivan, and Vigo Counties (ground water)
F. A. Watkins (g, Indianapolis, Ind.)
Fountain, Montgomery, Parke, Putnam, and Vermillion Counties (ground water)
F. A. Watkins (g, Indianapolis, Ind.)
Bunker Hill Air Force Base (ground water)
F. A. Watkins (g, Indianapolis, Ind.)

Iowa:
Coal resources of Iowa
E. R. Landis (D)
*Stratigraphy of the lead-zinc district near Dubuque
J. W. Whitlow (W)
*Wisconsin zinc-lead mining district
J. W. Whitlow (W)
Central Iowa aeromagnetic survey
J. R. Henderson (W)
*Omaha-Council Bluffs and vicinity, Nebraska and Iowa (urban geology)
R. D. Miller (D)
Low-flow frequency studies
H. H. Schwob (s, Iowa City, Iowa)
Channel-geometry studies (surface water)
H. H. Schwob (s, Iowa City, Iowa)
Flood profiles and flood frequency studies
H. H. Schwob (s, Iowa City, Iowa)
Floods from small areas
H. H. Schwob (s, Iowa City, Iowa)
The Mississippian aquifer of Iowa
W. L. Steinhilber (g, Iowa City, Iowa)
Cerro Gordo County (ground water)
W. L. Steinhilber (g, Iowa City, Iowa)
Linn County (ground water)
R. E. Hansen (g, Iowa City, Iowa)

Kansas:
Trace elements in rocks of Pennsylvanian age, Oklahoma, Kansas, Missouri (uranium, phosphate)
W. Danilchik (Quetta, Pakistan)
Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
Paleozoic stratigraphy of the Sedgwick Basin (oil and gas)
W. L. Adkison (Lawrence, Kans.)
*Shawnee County (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
*Wilson County (oil and gas)
H. C. Wagner (M)
Flood investigations
L. W. Furness (s, Topeka, Kans.)
Effects of sediment characteristics on fluvial morphology hydraulics
S. A. Schumm (h, D)
Northwestern Kansas (ground water)
S. W. Fader (g, Lawrence, Kans.)
Southwestern Kansas (ground water)
S. W. Fader (g, Lawrence, Kans.)

Kansas—Continued
Brown County (ground water)
C. K. Bayne (g, Lawrence, Kans.)
Cowley County (ground water)
C. K. Bayne (g, Lawrence, Kans.)
Decatur County (ground water)
J. M. McNellis (g, Lawrence, Kans.)
Ellsworth County (ground water)
W. Ives (g, Lawrence, Kans.)
Finney, Kearny, and Hamilton Counties (ground water)
S. W. Fader (g, Lawrence, Kans.)
Grant and Stanton Counties (ground water)
S. W. Fader (g, Lawrence, Kansas)
Johnson County (ground water)
H. G. O'Connor (g, Lawrence, Kans.)
Linn County (ground water)
W. J. Seevers (g, Lawrence, Kans.)
Miami County (ground water)
D. M. Miller (g, Lawrence, Kans.)
Neosho County (ground water)
W. J. Jungman (g, Lawrence, Kans.)
Montgomery County (ground water)
H. G. O'Connor (g, Lawrence, Kans.)
Pratt County (ground water)
C. W. Lane (g, Lawrence, Kans.)
Rush County (ground water)
J. McNellis (g, Lawrence, Kans.)
Sedgwick County (ground water)
C. W. Lane (g, Lawrence, Kans.)
Trego County (ground water)
W. G. Hodson (g, Lawrence, Kans.)
Wallace County (ground water)
W. G. Hodson (g, Lawrence, Kans.)
Fluvial sediment in the Arkansas River basin
James C. Mundorff (q, Lincoln, Nebr.)
Sedimentation in the Little Arkansas River basin
J. C. Mundorff (q, Lincoln, Nebr.)
Fluvial sediment in the Lower Kansas River basin
J. C. Mundorff (q, Lincoln, Nebr.)
Chemical quality of water in the South Fork Ninnescah River basin
A. M. Diaz (q, Lincoln, Nebr.)
Chemical quality of surface waters and sedimentation in the Saline River drainage basin
P. R. Jordan (q, Lincoln, Nebr.)
Chemical quality of water in the Walnut River basin
Robert F. Leonard (q, Lincoln, Nebr.)
Emergency water supplies in the Wichita area
C. W. Lane (g, Lawrence, Kans.)

Kentucky:
*Geologic mapping in Kentucky
P. W. Richards (Lexington, Ky.)
Geologic development of the Ohio River valley
L. L. Ray (W)
*Quaternary geology of the Owensboro quadrangle, Kentucky-Indiana
L. L. Ray (W)
Clay deposits of the Olive Hill bed of eastern Kentucky
J. W. Hosterman (W)
*Eastern Kentucky coal investigations
K. J. Englund (W)
Fluorspar deposits of northwestern Kentucky
R. D. Trace (Princeton, Ky.)

Kentucky—Continued
*Geology of the southern Appalachian folded belt, Kentucky, Tennessee, and Virginia
L. D. Harris (W)
Geophysical studies in Kentucky
J. S. Watkins (W)
Aerial radiological monitoring surveys, Oak Ridge National Laboratory area
R. G. Bates (W)
Public and industrial water supplies of Kentucky
H. T. Hopkins (g, Louisville, Ky.)
Geochemistry of natural waters of Kentucky
G. E. Hendrickson (g, Louisville, Ky.)
Hydrology of large springs in Kentucky
T. W. Lambert (g, Louisville, Ky.)
Flood-frequency study
J. A. McCabe (s, Louisville, Ky.)
Bridge-site studies (surface water)
C. H. Hannum (s, Louisville, Ky.)
Low-flow frequency and flow duration
J .A. McCabe (s, Louisville, Ky.)
Drainage-area compilation
H. C. Beaber (s, Louisville, Ky.)
Rainfall-runoff relations
J. A. McCabe (s, Louisville, Ky.)
Study of the hydrologic and related effects of strip mining in Beaver Creek watershed
J. J. Musser (q, Columbus, Ohio)
Alluvial terraces of the Ohio River (ground water)
W. E. Price (g, Louisville, Ky.)
Jackson Purchase area (ground water)
L. M. MacCary (g, Louisville, Ky.)
Louisville area (ground water)
E. A. Bell (g, Louisville, Ky.)
Mammoth Cave area (water resources)
G. E. Hendrickson (g, Louisville, Ky.)

Louisiana:
Flood investigations
L. V. Page (s, Baton Rouge, La.)
Water-supply characteristics of Louisiana streams
L. V. Page (s, Baton Rouge, La.)
Public water supplies in Louisiana
J. L. Snider (g, Baton Rouge, La.)
Compilation of quality of surface water records in Louisiana
S. F. Kapustka (q, Baton Rouge, La.)
Southeastern Louisiana (ground water)
M. D. Winner (g, Baton Rouge, La.)
Southwestern Louisiana (ground water)
A. H. Harder (g, Baton Rouge, La.)
Bossier-Caddo Parishes (water resources)
L. V. Page (s, Baton Rouge, La.)
Bossier and Caddo Parishes (ground water)
H. C. May (g, Baton Rouge, La.)
East and West Feliciana Parishes (ground water)
C. O. Morgan (g, Baton Rouge, La.)
Natchitoches Parish (ground water)
R. Newcome (g, Baton Rouge, La.)
Rapides Parish (ground water)
R. Newcome (g, Baton Rouge, La.)
Rapides Parish (water resources)
L. V. Page (s, Baton Rouge, La.)
Red River Parish (ground water)
R. Newcome (g, Baton Rouge, La.)

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Louisiana—Continued
Sabine Parish (ground water)
R. Newcome (g, Baton Rouge, La.)
Vernon Parish (ground water)
J. E. Rogers (g, Baton Rouge, La.)
Baton Rouge area (ground water)
C. O. Morgan (g,. Baton Rouge, La.)
Baton Rouge-New Orleans valley area (ground water)
G. T. Cardwell (g, Baton Rouge, La.)
Trap efficiency of reservoir on Bayou Dupont watershed
S. F. Kapustka (q, Baton Rouge, La.)
Ouachita River basin (quality of surface waters)
D. E. Everette (q, Baton Rouge, La.)
Reconnaissance study, quality of water, vicinity of Monroe, La.
S. F. Kapustka (q, Baton Rouge, La.)
Tallulah area (ground water)
A. N. Turcan, Jr. (g, Baton Rouge, La.)

Maine:
*Regional Paleozoic stratigraphy
R. B. Neuman (W)
Aeromagnetic surveys
J. W. Allingham (W)
Gravity studies, northern Maine
M. F. Kane (W)
*Southeastern Aroostook County (manganese)
L. Pavlides (W)
*Attean quadrangle
A. L. Albee (Pasadena, Calif.)
*Bedrock geology of the Danforth, Forest, and Vanceboo quadrangles
D. M. Larrabee (W)
*Greenville quadrangle
G. H. Espenshade (W)
*Electromagnetic and geologic mapping in Island Falls quadrangle
F. C. Frischknecht (D)
*Kennebago Lake quadrangle
E. L. Boudette (W)
*Phillips quadrangle
R. H. Moench (D)
*Geophysical and geologic mapping in the Stratton quadrangle
A. Griscom (W)
*The Forks quadrangle
F. C. Canney and E. V. Post (D)
Coastal area of southwestern Maine (ground water)
G. C. Prescott (g, Augusta, Maine)

Maryland:
Clay deposits
M. M. Knechtel (W)
Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
S. K. Neuschel (W)
*Allegany County (coal)
W. de Witt, Jr. (W)
*Beltsville quadrangle (urban geology)
C. F. Withington (W)
Geophysical studies, Montgomery County
A. Griscom (W)
Engineering geology, Washington metropolitan area
H. W. Coulter (W)
Low-flow analyses
L. W. Lenfest (s, College Park, Md.)

Maryland—Continued
Mass movement and surface runoff in an upland wooded hillslope
L. B. Leopold (w, W)
Scour of river beds during high flow
L. B. Leopold (w, W)
Allegany and Washington Counties (ground water)
T. H. Slaughter (g, Baltimore, Md.)
Anne Arundel County (ground water)
F. K. Mack (g, Baltimore, Md.)
Charles County (ground water)
T. H. Slaughter (g, Baltimore, Md.)
Northern and western Montgomery County (ground water)
P. M. Johnston (g, Baltimore, Md.)
Prince Georges County (ground water)
F. K. Mack (g, Baltimore, Md.)
Fort George G. Meade (ground water)
E. G. Otton (g, Baltimore, Md.)
Potomac River basin (ground water)
P. M. Johnston (g, W)
Sharpsburg area (ground water)
E. G. Otton (g, Baltimore, Md.)

Massachusetts:
Geophysical studies in Massachusetts
R. W. Bromery (W)
Research and application of geology and seismology to public works planning
C. R. Tuttle and R. N. Oldale (Boston, Mass.)
Sea-cliff erosion studies
C. A. Kaye (Boston, Mass.)
Central Cape Cod, subsurface studies
R. N. Oldale, C. R. Tuttle, and C. Koteff (Boston, Mass.)
*Stratigraphy and structure of Taconic rocks
E-an Zen (W)
*Ashley Falls and Bashbish Falls quadrangles, Massachusetts and Connecticut, and Egremont quadrangle, Massachusetts; surficial geologic mapping
J. H. Hartshorn (Boston, Mass.)
*Assawompsett Pond quadrangle
C. Koteff (Boston, Mass.)
*Athol quadrangle
D. F. Eschman (Ann Arbor, Mich.)
*Ayer quadrangle; bedrock geologic mapping
R. H. Jahns (University Park, Pa.)
*Bellerica, Lowell, Tyngsboro, and Westford quadrangles
R. H. Jahns (University Park, Pa.)
*Blue Hills quadrangle
N. E. Chute (Syracuse, N.Y.)
*Clinton and Shrewsbury quadrangles; bedrock geologic mapping
R. F. Novotny (Boston, Mass.)
*Concord quadrangle
N. P. Cuppels and C. Koteff (Boston, Mass.)
*Duxbury and Scituate quadrangles
N. E. Chute (Syracuse, N.Y.)
*Georgetown quadrangle
N. P. Cuppels (Boston, Mass.)
*Greenfield quadrangle; surficial geologic mapping
R. H. Jahns (University Park, Pa.)
*Lawrence, Reading, South Groveland, and Wilmington quadrangles; bedrock geologic mapping
R. O. Castle (Los Angeles, Calif.)
Norwood quadrangle
N. E. Chute (Syracuse, N.Y.)

Massachusetts—Continued
- *Plainfield quadrangle; bedrock geologic mapping
  - P. H. Osberg (Orono, Maine)
- *Reading and Salem quadrangles; surficial geologic mapping
  - R. N. Oldale (Boston, Mass.)
- *Rowe and Heath quadrangles, Massachusetts and Vermont
  - A. H. Chidester (D) and J. H. Hartshorn (Boston, Mass.)
- *Salem quadrangle; bedrock geologic mapping
  - P. Toulmin, III (W)
- *Southwick quadrangle, Massachusetts and Connecticut
  - R. W. Schnabel (D)
- *Springfield South quadrangle, Masschusetts and Connecticut
  - J. H. Hartshorn and C. Koteff (Boston, Mass.)
- *Taunton quadrangle
  - J. H. Hartshorn (Boston, Mass.)
- *West Springfield quadrangle, Massachusetts and Connecticut
  - R. B. Colton (D) and J. H. Hartshorn (Boston, Mass.)
- Low-flow characteristics
  - G. K. Wood (s, Boston, Mass.)
- Southeastern Massachusetts (ground water)
  - O. M. Hackett (g, Boston, Mass.)
- Western Massachusetts (ground water)
  - O. M. Hackett (g, Boston, Mass.)
- Assabet River basin (ground water),
  - R. G. Peterson (g, Boston, Mass.)
- Brockton-Pembroke area (ground water)
  - R. G. Peterson (g, Boston, Mass.)
- Ipswich River drainage basin (ground water)
  - J. A. Baker (g, Boston, Mass.)
- Lowell area (ground water)
  - O. M. Hackett (g, Boston, Mass.)
- Lower Merrimack valley (ground water)
  - J. A. Baker (g, Boston, Mass.)
- Wilmington-Reading area (ground water)
  - O. M. Hackett (g, Boston, Mass.)
- Parker and Rowley River drainage basins (ground water)
  - J. A. Baker (g, Boston, Mass.)
- Southern Plymouth County (ground water)
  - J. M. Weigle (g, Boston, Mass.)

Michigan:
- Geophysical studies in the Lake Superior region
  - G. D. Bath (M)
- *Lake Algonquin drainage
  - J. T. Hack (W)
- *Michigan copper district
  - W. S. White (W)
- *Southern Dickinson County (iron)
  - R. W. Bayley (M)
- *Eastern Iron County (iron)
  - K. L. Wier (D)
- *Iron River–Crystal Falls district (iron)
  - H. L. James (Minneapolis, Minn.)
- *East Marquette district (iron)
  - J. E. Gair (D)
- *Negaunee and Palmer quadrangles, (iron)
  - J. E. Gair (D)
- Alger County (ground water)
  - K. S. Vanlier (g, Lansing, Mich.)
- Battle Creek area (ground water)
  - M. Deutsch (g, Lansing, Mich.)
- North Branch Clinton River basin (surface water)
  - S. W. Wiitala (s, Lansing, Mich.)
- Elsie area (ground water)
  - K. E. Vanlier (g, Lansing, Mich.)

Michigan—Continued
- Jordan River National Fish Hatchery (ground water)
  - R. F. Brown (g, St. Paul, Minn.)
- Artificial recharge at Kalamazoo
  - J. E. Reed (g, Lansing, Mich.)
- Marquette Iron Range (water resources)
  - S. W. Wiitala (s, Lansing, Mich.)
- Menominee County (gound water)
  - K. E. Vanlier (g, Lansing, Mich.)

Minnesota:
- Geophysical studies in the Lake Superior region
  - G. D. Bath (M)
- Aerial radiological monitoring surveys, Elk River
  - J. A. Pitkin (W)
- *Cuyuna North Range (iron)
  - R. G. Schmidt (W)
- Flood-frequency analysis
  - C. H. Prior (s, St. Paul, Minn.)
- Small-area flood gaging
  - C. H. Prior (s, St. Paul, Minn.)
- Clay County (ground water)
  - R. F. Brown (g, St. Paul, Minn.)
- Kittson, Marshall, and Roseau Counties (ground water)
  - G. R. Schiner (g, St. Paul, Minn.)
- Nobles County and part of Jackson County (ground water)
  - R. F. Norvitch (g, St. Paul, Minn.)
- Water resources in the vicinity of municipalities in the Mesabi Range area
  - R. D. Cotter (g, St. Paul, Minn.)
- Surficial geology of Mesabi—Vermilion Iron Range
  - R. D. Cotter (g, St. Paul, Minn.)
- Bedrock topography of the eastern Mesabi Range area, St. Louis County
  - E. L. Oakes (g, St. Paul, Minn.)
- Bedrock topography of the western Mesabi Range, Itasca County
  - E. L. Oakes (g, St. Paul, Minn.)
- Aurora area (ground water)
  - R. W. Maclay (g, St. Paul, Minn.)
- Duluth Air Force Base (ground water)
  - J. E. Rogers (g, St. Paul, Minn.)
- Grand Rapids area (ground water)
  - E. L. Oakes (g, St. Paul, Minn.)
- Hibbing area (ground water)
  - R. F. Norvitch (g, St. Paul, Minn.)
- Mountain Iron-Virginia area (ground water)
  - R. D. Cotter (g, St. Paul, Minn.)
- Nett Lake area (ground water)
  - R. F. Norvitch (g, St. Paul, Minn.)
- Redwood Falls area (ground water)
  - G. R. Schiner (g, St. Paul, Minn.)
- Twin Cities area (ground water)
  - R. F. Brown (g, St. Paul, Minn.)

Mississippi:
- Mesozoic rocks of Florida and eastern Gulf coast
  - E. R. Applin (Jackson, Miss.)
- Pre-Selma Cretaceous rocks of Alabama and adjacent States
  - L. C. Conant (Tripoli, Libya)
- Oligocene gastropods and pelecypods
  - F. S. MacNeil (M)
- Geologic and hydrologic environment of Tatum salt dome (test-site evaluation)
  - W. S. Twenhofel (D)

Mississippi—Continued
Drainage-area determination
J. D. Shell (s, Jackson, Miss.)
Floods from small basins
K. V. Wilson (s, Jackson, Miss.)
Bridge-site studies (surface water)
K. V. Wilson (s, Jackson, Miss.)
Low-flow characteristics
H. G. Golden (s, Jackson, Miss.)
Salt-water encroachment along the Mississippi Gulf coast
J. W. Lang (g, Jackson, Miss.)
Southwestern Mississippi (water resources)
E. J. Harvey (g, Jackson, Miss.)
Cretaceous aquifers in Mississippi
J. W. Lang (g, Jackson, Miss.)
Alcorn County (ground water)
E. H. Boswell (g, Jackson, Miss.)
Lauderdale County (ground water)
E. H. Boswell (g, Jackson, Miss.)
Geohydrologic studies of salt domes with emphasis on Tatum Dome
C. A. Armstrong (g, Jackson, Miss.)
Delta area (ground water)
B. E. Wasson (g, Jackson, Miss.)
Pascagoula River basin (ground water)
E. J. Harvey (g, Jackson, Miss.)
Water resources of Pascagoula River basin
E. J. Harvey (g, Jackson, Miss.)
Pearl River basin (ground water)
B. E. Ellison (g, Jackson, Miss.)

Missouri:
Trace elements in rocks of Pennsylvanian age, Oklahoma, Kansas, Missouri (uranium, phosphate)
W. Danilchik (Quetta, Pakistan)
*Lead deposits of southeastern Missouri
T. H. Kiilsgaard (W)
Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
Correlation of aeromagnetic studies and areal geology, southeast Missouri
J. W. Allingham (W)
Terrestrial impact structures, Decaturville Dome
D. J. Milton (M)
Sediment transport, Mississippi River at St. Louis, Mo.
P. R. Jordan (q, Lincoln, Nebr.)
Flood investigations on small areas
E. H. Sandhaus (s, Rolla, Mo.)
Low-flow characteristics of Missouri streams
H. C. Bolon (s, Rolla, Mo.)

Montana:
General geology:
Mesozoic stratigraphic paleontology of northwestern Montana
W. A. Cobban (D)
Stratigraphy of the Belt Series
C. P. Ross (D)
Chemical and physical properties of the Pierre Shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
*Alice Dome–Sumatra area
H. R. Smith (D)
*Petrology of the Bearpaw Mountains
W. T. Pecora (W)

Montana—Continued
General geology—Continued
*Geochemistry and metamorphism of the Belt Series, Clark Fork and Packsaddle Mountain quadrangles, Idaho and Montana
J. E. Harrison (D)
*Big Sandy Creek area
R. M. Lindvall (D)
*Quaternary geology of the Browning area and the east slope of Glacier National Park
G. M. Richmond (D)
*Duck Creek Pass quadrangle
W. H. Nelson (Hopkinsville, Ky.)
*Gravelly Range–Madison Range
J. B. Hadley (W)
Earthquake investigations, Hebgen Lake
J. B. Hadley (W) and I. J. Witkind (D)
*Maudlow quadrangle
B. Skipp (D)
*Morrison Lake quadrangle, Montana and Idaho
E. T. Cressman (Lexington, Ky.)
Petrology and chromite resources of the Stillwater ultramafic complex
E. D. Jackson (W)
*Sun River Canyon area
M. R. Mudge (D)
*Tepee Creek quadrangle
I. J. Witkind (D)
*Three Forks quadrangle
G. D. Robinson (D)
*Toston quadrangle
G. D. Robinson (D)
*Willis quadrangle
W. B. Myers (D)
*Petrology of the Wolf Creek area
R. G. Schmidt (W)
Mineral resources:
Ore deposits of southwestern Montana
H. L. James (Minneapolis, Minn.)
*Boulder batholith area (base, precious, and radioactive metals)
M. R. Klepper (W)
Manganese deposits of the Philipsburg area (manganese and base metals)
W. C. Prinz (W)
*Thunder Mountain niobium area, Montana and Idaho
R. L. Parker (D)
*Livingston–Trail Creek area (coal)
A. E. Roberts (D)
Powder River coal fields
R. P. Bryson (W)
Stratigraphy and resources of the Phosphoria Formation in southwestern Montana (phosphate, minor elements)
E. R. Cressman (Lexington, Ky.)
Phosphate deposits of south-central Montana
R. W. Swanson (Spokane, Wash.)
*Geology of the Winnett-Mosby area (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota and South Dakota
C. A. Sandberg (D)

Montana—Continued
Engineering geology:
*Great Falls area (urban geology)
R. W. Lemke (D)
*Wolf Point area (construction-site planning)
R. B. Colton (D)
*Fort Peck area (construction-site planning)
H. D. Varnes (D)
Geology of the Williston Basin with reference to the disposal of high-level radioactive wastes
C. A. Sandberg (D)
Geophysical studies:
Geophysical studies, Pacific Northwest
W. E. Davis (M)
Gravity and magnetic studies, western Montana
W. T. Kinoshita (M)
Correlation of aeromagnetic studies and areal geology, Bearpaw Mountains
K. G. Books (W)
Aeromagnetic and gravity studies of the Boulder batholith
W. E. Davis (M)
Water resources:
Floods from small areas
F. C. Boner (s, Helena, Mont.)
Effects of sediment on the propagation of trout in small streams
A. R. Gustafson (q, Worland, Wyo.)
Study of water application and use on a range water spreader in northeast Montana
F. A. Branson (h, D)
Hailstone, Halfbreed, and Lake Mason Wildlife Refuges (ground water)
F. A. Swenson, (g, Billings, Mont.)
Bitterroot Valley, Ravalli County (ground water)
R. G. McMurtrey (g, Billings, Mont.)
Lower Bighorn River valley (Hardin Unit) (ground water)
L. J. Hamilton (g, Billings, Mont.)
Northeastern Blaine County (ground water)
E. A. Zimmerman (g, Billings, Mont.)
Blue Water Springs area (ground water)
F. A. Swenson (g, Billings, Mont.)
Deer Lodge Valley (ground water)
R. L. Konizeski (g, Billings, Mont.)
Fort Belknap Indian Reservation (ground water)
D. C. Alverson (g, Billings, Mont.)
Southern part of the Judith Basin (ground water)
E. A. Zimmerman (g, Billings, Mont.)
Milk River bottoms, Fort Belknap area (ground water)
W. B. Hopkins (g, Billings, Mont.)
Missoula Valley (ground water)
R. G. McMurtrey (g, Billings, Mont.)
Two Medicine irrigation project (ground water)
Q. F. Paulson (g, Billings, Mont.)

Nebraska:
Chemical and physical properties of the Pierre Shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
*Lower Republican River
R. D. Miller (D)
*Valley County
R. D. Miller (D)
Central Nebraska basin (oil and gas)
G. E. Prichard (D)

Nebraska—Continued
Omaha–Council Bluffs and vicinity, Nebraska and Iowa (urban geology)
R. D. Miller (D)
Peak discharges from small areas
E. W. Beckman (s, Lincoln, Nebr.)
Bridge-site studies (surface water)
E. W. Beckman (s, Lincoln, Nebr.)
Investigation of some sedimentation charactersisics of a sand-bed stream
D. M. Culbertson (q, Lincoln, Nebr.)
Evapotranspiration study
O. E. Leppanen (h, Phoenix, Ariz.)
Erosion, sedimentation, and landform development in arid and semi-arid regions
G. G. Parker, R. C. Miller, and I. S. McQueen (h, D)
Trap efficiencies of reservoir 1 and 1A, Brownell Creek Subwatershed
J. C. Mundorff (q, Lincoln, Nebr.)
Hall County (ground water)
C. F. Keech (g, Lincoln, Nebr.)
Hamilton County (ground water)
C. F. Keech (g, Lincoln, Nebr.)
York County (ground water)
C. F. Keech (g, Lincoln, Nebr.)
Channel patterns and terraces of the Loup Rivers in Nebraska
J. C. Brice (q, Lincoln, Nebr.)
Erosion and deposition in Medicine Creek basin, Nebraska
J. C. Brice (q, Lincoln, Nebr.)
Quality of water in the Niobrara River basin
Cloyd H. Scott (q, Lincoln, Nebr.)
Ground water near the Platte River south of Chapman
C. F. Keech (g, Lincoln, Nebr.)
Cedar River valley in the lower Platte River basin (ground water)
J. B. Hyland (g, Lincoln, Nebr.)
Upper Salt Creek drainage basin (ground water)
C. F. Keech (g, Lincoln, Nebr.)

Nevada:
General geology:
**Clark County
C. R. Longwell (M)
**Esmeralda County
J. P. Albers (M)
**Eureka County
R. J. Roberts (M)
**Humboldt County
C. R. Willden (M)
**Lincoln County
C. M. Tschanz (La Paz, Bolivia)
*Lyon, Douglas, and Ormsby Counties
J. G. Moore (Hilo, Hawaii)
**Northern Nye County
F. J. Kleinhampl (M)
**Southern Nye County
H. R. Cornwall (M)
**Pershing County
D. B. Tatlock (M)
*Ash Meadows quadrangle, California and Nevada
C. S. Denny (W)
*Cortez quadrangle
J. Gilluly (D)

Nevada—Continued
General geology—Continued
*Eureka quadrangle
T. B. Nolan (W)
*Fallon area
R. B. Morrison (D)
*Frenchie Creek quadrangle
L. J. P. Muffler (D)
*Horse Creek Valley quadrangle
H. Masursky (D)
*Lower Mesozic stratigraphy and paleontology, Humboldt Range
N. J. Silberling (M)
*Jarbidge area, Nevada and Idaho
R. R. Coats (M)
*Kobeh Valley
C. W. Merriam (W)
*Las Vegas–Lake Mead area
C. R. Longwell (M)
*Mt. Lewis and Crescent Valley quadrangles
J. Gilluly (D)
*Pinto Summit and Bellevue Peak quadrangles
T. B. Nolan (W)
*Railroad mining district, and the Dixie Flats, Pine Valley, and Robinson Mountain quadrangles
J. F. Smith, Jr. (D)
*Schell Creek Range
H. D. Drewes (D)
Northern Sonoma Range
J. Gilluly (D)
*Owyhee and Mt. City quadrangles, Nevada and Idaho
R. R. Coats (M)
Mineral resources:
Western oxidized-zinc deposits
A. V. Heyl (W)
Geochemical halos of mineral deposits, Utah and Nevada
R. L. Erickson (D)
*Antler Peak quadrangle (base and precious metals)
R. J. Roberts (M)
Distribution of beryllium, Mt. Wheller mine area
D. E. Lee (M)
Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
W. C. Smith (M)
*Regional geologic setting of the Ely district (copper, lead, zinc)
A. L. Brokaw (D)
*Beatty area (fluorite, bentonite, gold, silver)
H. R. Cornwall (M)
Iron-ore deposits
R. G. Reeves (Alegro, Brazil)
*Unionville and Buffalo Mountain quadrangles, Humboldt Range (iron, tungsten, silver, quicksilver)
R. E. Wallace (M)
Ione quadrangle (lead, quicksilver, tungsten)
C. J. Vitaliano (Bloomington, Ind.)
Stratigraphy and resources of the Phosphoria and Park City Formations in Utah and Nevada (phosphate, minor elements)
K. M. Tagg (M)
*Wheeler Peak and Garrison quadrangles, Snake Range (tungsten, beryllium)
D. H. Whitebread (M)

Nevada—Continued
Mineral resources—Continued
*Osgood Mountains quadrangle (tungsten, quicksilver)
P. E. Hotz (M)
*Eureka mining district (zinc, lead, silver, gold)
T. B. Nolan (W)
Engineering geology and geophysical studies:
Central Nevada geophysical studies
D. R. Mabey (M)
Gravity investigations, Clark County
M. F. Kane (W)
Geophysical studies of Nevada Test Site
R. M. Hazelwood (D)
Aeromagnetic surveys, Nevada Test Site
W. J. Dempsey (W)
Aerial radiological monitoring surveys, Nevada Test Site
J. L. Meuschke (W)
*Geologic and hydrologic environment, Nevada Test Site
F. A. McKeown (D)
*Engineering geology of the Nevada Test Site area
V. R. Wilmarth (D)
Post-shot investigations, Nevada Test Site
V. R. Wilmarth (D)
Buckboard Mesa basalt studies, Nevada Test Site
V. R. Wilmarth (D)
Rainier Mesa–Climax stock investigations, Nevada Test Site
V. R. Wilmarth (D)
Site evaluation, underground air storage, Nevada Test Site
R. B. Johnson (D)
Yucca Valley and Frenchman Valley engineering geology, Nevada Test Site
F. N. Houser (D)
Water resources:
Flood investigations
E. E. Harris (s, Carson City, Nevada)
Statewide reconnaissance of ground-water basins
T. E. Eakin (g, Carson City, Nev.)
Northwestern basins (ground water)
W. C. Sinclair (g, Carson City, Nev.)
Nevada Test Site (ground water)
S. L. Schoff (g, D)
Desert valley (ground water)
W. C. Sinclair (g, Carson City, Nev.)
Fernley-Wadsworth area (ground water)
W. C. Sinclair (g, Carson City, Nev.)
Fillmore County (ground water)
C. F. Keech (g, Lincoln, Nebr.)
Granite Basin (ground water)
W. C. Sinclair, (g, Carson City, Nev.)
Hydrology of a portion of the Humboldt River valley
T. W. Robinson (h, M)
Kings River valley (ground water)
C. P. Zones (g, Carson City, Nev.)
Las Vegas basin (ground water)
G. T. Malmberg (g, Carson City, Nev.)
Long Valley (ground water)
W. C. Sinclair (g, Carson City, Nev.)
Pahrump Valley (ground water)
G. T. Malmberg (g, Carson City, Nev.)
Pine Forest Valley (ground water)
W. C. Sinclair (g, Carson City, Nev.)
Lower Reese River valley (ground water)
O. J. Loeltz (g, Carson City, Nev.)

Nevada—Continued
Water resources—Continued
Sarcobatus Flat, Nye County (ground water)
G. T. Malmberg (g, Carson City, Nev.)
Truckee Meadows (ground water)
O. J. Loeltz (g, Carson City, Nev.)
New Hampshire:
Uranium and thorium in the White Mountain magma series
A. P. Butler, Jr. (D)
Seacoast region (ground water)
J. M. Weigle (g, Boston, Mass.)
Hydrology of small streams
C. E. Knox (s, Boston, Mass.)
Lower Merrimack River basin (ground water)
J. M. Weigle (g, Boston, Mass.)
New Jersey:
*Lower Delaware River basin, New Jersey and Pennsylvania
J. P. Owens (W)
*Middle Delaware River basin, New Jersey and Pennsylvania
A. A. Drake, Jr. (W)
Correlation of aeromagnetic studies and aerial geology, New York-New Jersey Highlands
A. Jesperson (W)
Flood and base-flow gaging
E. G. Miller (s, Trenton, N.J.)
Flood-plain inundation studies
R. H. Tice (s, Trenton, N.J.)
Streamflow records analyzed by electronic computer
E. G. Miller (s, Trenton, N.J.)
Flow probability of New Jersey streams
E. G. Miller (s, Trenton, N.J.)
Flood data
J. E. McCall (s, Trenton, N.J.)
Flood warning
J. E. McCall (s, Trenton, N.J.)
Chloride in ground water
P. R. Seaber (g, Trenton, N.J.)
Geochemistry of ground water in the English Formation
P. R. Seaber (g, Trenton, N.J.)
Quality of water, Delaware River, Trenton, New Jersey
L. T. McCarthy, Jr. (q, Philadelphia, Pa.)
Trap efficiency of the Baldwin Creek reservoir
J. R. George (q, Harrisburg, Pa.)
Raritan River basin (quality of surface water)
J. R. George (q, Harrisburg, Pa.)
Burlington County (ground water)
F. E. Rush (g, Trenton, N.J.)
Camden County (ground water)
E. Donsky (g, Trenton, N.J.)
Cape May County (ground water)
H. E. Gill (g, Trenton, N.J.)
Essex County (ground water)
J. Vecchioli (g, Trenton, N.J.)
Gloucester County (ground water)
W. F. Hardt (g, Trenton, N.J.)
Mercer County (ground water)
J. Vecchioli (g, Trenton, N.J.)
Monmouth County (ground water)
A. Sinnott (g, Trenton, N.J.)
Morris County (ground water)
H. E. Gill (g, Trenton, N.J.)
Ocean County (ground water)
C. A. Appel (g, Trenton, N.J.)

New Jersey—Continued
Salem County (ground water)
J. C. Rosenau (g, Trenton, N.J.)
Passaic Valley (ground water)
J. Vecchioli (g, Trenton, N.J.)
Phillipsburg area (ground water)
J. R. Randolph (g, Trenton, N.J.)
Pine Barrens (ground water)
E. C. Rhodehamel (g, Trenton, N.J.)
Rahway area (ground water)
H. R. Anderson (g, Trenton, N.J.)
Sayreville area (ground water)
C. A. Appel (g, Trenton, N.J.)
Fluvial sedimentation in the Stony Book watershed, Princeton
J. R. George (q, Harrisburg, Pa.)
Wharton Tract (ground water)
E. C. Rhodehamel (g, Trenton, N.J.)
New Mexico:
General geology:
State geologic map
C. H. Dane (W)
**Photogeologic mapping
A. B. Olson (W)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
Lithologic studies, Colorado Plateau
R. A. Cadigan (D)
Clay studies, Colorado Plateau
L. G. Schultz (D)
Diatremes, Navajo and Hopi Indian Reservations
E. M. Shoemaker (M)
*Upper Gila River basin, Arizona and New Mexico
R. B. Morrison (D)
Guadalupe Mountains
P. T. Hayes (D)
*Manzano Mountains
D. A. Myers (D)
*Southern Oscura, northern San Andres Mountains
G. O. Bachman (D)
*Philmont Ranch quadrangle
G. D. Robinson (D)
*Petrology of the Valles Mountains
R. L. Smith (W)
Mineral resources:
Geochemical halos of mineral deposits, Arizona and New Mexico
L. C. Huff (D)
Colorado Plateau botanical-prospecting studies
F. J. Kleinhampl (M)
Botanical research, San Juan County
H. L. Cannon (D)
*Animas River area, Colorado and New Mexico (coal, oil, and gas)
H. Barnes (D)
*Raton Basin coking coal
G. H. Dixon (D)
*Western Raton coal basin
C. L. Pillmore (D)
*East side San Juan Basin (coal, oil and gas)
C. H. Dane (W)
Oil and gas fields
D. C. Duncan (W)

New Mexico—Continued
Mineral resources—Continued
*Franklin Mountains, New Mexico and Texas (petroleum)
R. L. Harbour (D)
*Silver City region (copper, zinc)
W. R. Jones (D)
Potash and other saline deposits of the Carlsbad area
C. L. Jones (M)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Relative concentrations of chemical elements in different rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
Regional relation of the uranium deposits of northwestern New Mexico
L. S. Hilpert (Salt Lake City, Utah)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (M)
San Rafael Group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (W)
Ambrosia Lake district (uranium)
H. C. Granger (D)
*Carrizo Mountains area, Arizona and New Mexico (uranium)
J. D. Strobell (D)
*Grants area (uranium)
R. E. Thaden (Columbia, Ky.)
Mineralogy of uranium-bearing rocks in the Grants area
A. D. Weeks (W)
*Laguna district (uranium)
R. H. Moench (D)
Alteration in relation to uranium deposits, Laguna district
R. H. Moench (D)
Engineering geology and geophysical studies:
*Engineering geology of Gnome Test Site
L. M. Gard (D)
*Nash Draw quadrangle (test-site evaluation)
J. D. Vine (M)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Geophysical studies in the Upper Rio Grande
G. E. Andreasen (W)
Aerial radiological monitoring surveys, Gnome test site
J. A. MacKallor (W)
Water resources:
Flood-frequency relations
L. A. Wiard (s, Santa Fe, N. Mex.)
Hydrologic almanac of State
W. E. Hale (g, Albuquerque, N. Mex.)
Use of water by muncipalities
G. A. Dinwiddle (g, Albuquerque, N. Mex.)
Recharge studies on the High Plains
J. S. Havens (g, Albuquerque, N. Mex.)
Tritium as a tracer in the Ogallala Formation in the High Plains, Lea County
H. O. Reeder (g, Albuquerque, N. Mex.)

New Mexico—Continued
Water resources—Continued
Effects of sediment characteristics on fluvial morphology hydraulics
S. A. Schumm (h, D)
Piping, an erosional phenomenon in certain silty soils of arid and semi-arid regions
G. G. Parker, R. C. Miller and I. S. McQueen (h, D)
Study of precipitation runoff and sediment yield in Cornfield Wash
D. E. Burkham (h, Albuquerque, N. Mex.)
Scour of river beds during high flow
L. B. Leopold (w, W)
Particle movement and channel scour and fill of an ephemeral arroyo near Santa Fe
L. B. Leopold (w, W)
Maps showing quality of water by counties
F. D. Trauger (g, Albuquerque, N. Mex.)
Grant County (ground water)
F. D. Trauger (g, Albuquerque, N. Mex.)
Guadalupe County (ground water)
A. Clebsch, Jr. (g, Albuquerque, N. Mex.)
Southern Luna County (ground water)
G. C. Doty (g, Albuquerque, N. Mex.)
Southeastern McKinley County (ground water)
J. B. Cooper (g, Albuquerque, N. Mex.)
Quay County (ground water)
F. D. Trauger (g, Albuquerque, N. Mex.)
Northern San Juan County (ground water)
F. D. Trauger (g, Albuquerque, N. Mex.)
Eastern Valencia County (ground water)
F. B. Titus (g, Albuquerque, N. Mex.)
Canoncito School facility (ground water)
B. W. Maxwell (g, Albuquerque, N. Mex.)
Carlsbad area (ground water)
L. J. Bjorklund (g, Albuquerque, N. Mex.)
Gallup area (ground water)
S. W. West (g, Albuquerque, N. Mex.)
Ground-water studies in conjunction with project Gnome, Eddy County
J. B. Cooper (g, Albuquerque, N. Mex.)
Hondo Valley (ground water)
W. A. Mourant (g, Albuquerque, N. Mex.)
Southern Jicarilla Indian Reservation (ground water)
E. H. Baltz (g, Albuquerque, N. Mex.)
Northern Lea County (ground water)
H. O. Reeder (g, Albuquerque, N. Mex.)
Water supply for Los Alamos
R. L. Cushman (g, Albuquerque, N. Mex.)
Los Alamos area (ground water)
R. L. Cushman (g, Albuquerque, N. Mex.)
Evaluation of well-field data at Los Alamos
R. L. Cushman (g, Albuquerque, N. Mex.)
Waste-contamination studies at Los Alamos (ground water)
J. H. Abrahams (g, Albuquerque, N. Mex.)
Movement of water and radioactive materials in the Bandelier Tuff, Los Alamos
J. H. Abrahams (g, Albuquerque, N. Mex.)
Tritium as a tracer in the Lake McMillan underground reservoir
H. O. Reeder (g, Albuquerque, N. Mex.)
McMillan delta area (ground water)
E. R. Cox (g, Albuquerque, N. Mex.)

New Mexico—Continued
Water resources—Continued
Ground-water conditions between Lake McMillan and Carlsbad Springs
E. R. Cox (g, Albuquerque, N. Mex.)
Mortandad Canyon (ground water)
R. L. Cushman (g, Albuquerque, N. Mex.)
Feasibility of Queen Lake as a disposal area for brine
E. R. Cox (g, Albuquerque, N. Mex.)
Rio Grande basin (surface water)
W. L. Heckler (s, Santa Fe, N. Mex.)
Rio Grande Valley near Hot Springs (ground water)
E. R. Cox (g, Albuquerque, N. Mex.)
Tritium in ground water in the Roswell Basin
J. W. Hood (g, Albuquerque, N. Mex.)
Ground-water pumpage in the Roswell Basin
R. M. Mower (g, Albuquerque, N. Mex.)
Ground-water recharge in the Roswell Basin
R. L. Cushman (g, Albuquerque, N. Mex.)
Sandia and Manzano Mountains area (ground water)
F. B. Titus (g, Albuquerque, N. Mex.)
Three Rivers area (ground water)
J. W. Hood (g, Albuquerque, N. Mex.)
Ground-water structural basins west of Tucumcari
F. D. Trauger (g, Albuquerque, N. Mex.)
Walker Air Force Base (ground water)
J. W. Hood (g, Albuquerque, N. Mex.)
Northern White Sands Integrated Range (ground water)
J. E. Weir (g, Albuquerque, N. Mex.)

New York:
*Selected iron deposits of the Northeastern States
A. F. Buddington (Princeton, N.J.)
Correlation of aeromagnetic studies and areal geology, Adirondacks area
J. R. Balsley (W)
Correlation of aeromagnetic studies and areal geology, New York–New Jersey Highlands
A. Jespersen (W)
*Surficial geology of Dannemora and Plattsburgh quadrangles
C. S. Denny (W)
Stratigraphy of the Dunkirk and related beds, New York
W. de Witt, Jr. (W)
*Glacial geology of the Elmira-Williamsport area, New York and Pennsylvania
C. S. Denny (W)
Metamorphism and origin of mineral deposits, Gouverneur area
A. E. J. Engel (Pasadena, Calif.)
*Mooers and Ohio quadrangles
D. R. Wiesnet (W)
*Richville quadrangle
H. M. Bannerman (W)
*Stratigraphy and structure of Taconic rocks
E-an Zen (W)
Recognition of late glacial substages in New England and New York
J. E. Upson (g, Mineola, N.Y.)
Small streams (surface water)
O. P. Hunt (s, Albany, N. Y.)
Flood and low-flow gaging, Rockland County
G. R. Ayer (s, Albany, N. Y.)
Low-flow analysis
B. Dunn (s, Albany, N.Y.)

New York—Continued
Chemical quality of Glowegee Creek at AEC reservation near West Milton
F. H. Pauszek (q, Albany, N.Y.)
Chemical and physical quality of water resources in the Housatonic River basin
E. H. Salvas (q, Albany, N.Y.)
St. Lawrence River basin (chemical and physical quality of water resources)
A. L. Mattingly (q, Albany, N.Y.)
Experimental recharge basin (surface water)
R. M. Sawyer (s, Albany, N.Y.)
Delaware County (ground water)
J. Soren (g, Albany, N.Y.)
Cadmium-chromium contamination in ground water in Nassau County
N. J. Lusczynski (g, Albany, N. Y.)
Northeast Nassau County (ground water)
J. Isbister (g, Albany, N.Y.)
Nassau County (ground water)
N. M. Perlmutter (g, Mineola, N.Y.)
Salt-water encroachment in southern Nassau County
N. J. Lusczynski (g, Albany, N.Y.)
Orange and Ulster Counties (ground water)
R. D. Duryea (g, Albany, N.Y.)
Queens County (ground water)
N. M. Perlmutter (g, Albany, N.Y.)
Schodack terrace, Rensselaer County (ground water)
J. Joyce (g, Albany, N.Y.)
Saratoga County (ground water)
R. C. Heath (g, Albany, N.Y.)
Eastern Schenectady County (ground water)
J. D. Winslow (g, Albany, N.Y.)
Mid-island area, western Suffolk County (ground water)
N. M. Perlmutter (g, Albany, N.Y.)
Babylon-Islip area, Suffolk County (ground water)
I. H. Kantrowitz (g, Albany, N.Y.)
Babylon-Islip area (surface water)
E. J. Pluhowski (s, Albany, N.Y.)
Huntington-Smithton area (ground water)
E. R. Lubke (g, Albany, N.Y.)
Jamestown area (ground water)
R. A. Wilkens (g, Albany, N.Y.)
Massena-Waddington area (ground water)
F. W. Trainer (g, Albany, N.Y.)
Montauk Air Force Station (ground water)
N. M. Perlmutter (g, Albany, N.Y.)
Niagara Frontier (ground water)
R. H. Johnston (g, Albany, N.Y.)
Southhold (ground water)
H. C. Crandell (g, Albany, N.Y.)
Syracuse area (ground water)
J. A. Tannenbaum (g, Albany, N.Y.)
West Milton well field
J. D. Winslow (g, Albany, N.Y.)
West Milton area (ground water)
F. K. Mack (g, Albany, N.Y.)

North Carolina:
Mica deposits of the southern Blue Ridge Mountains
F. G. Lesure (W)
*Investigations of the Volcanic Slate Series
A. A. Stromquist (D)
Concord quadrangle, geophysical studies
R. G. Bates (W)

North Carolina—Continued
Massive sulfide deposits of the Ducktown district, Tennessee and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)
*Grandfather Mountain
B. H. Bryant (D)
*Great Smoky Mountains, Tennessee and North Carolina
J. B. Hadley (D)
*Hamme tungsten deposit
J. M. Parker, 3d (Raleigh, N.C.)
*Mount Rogers area, Virginia, North Carolina, and Tennessee
D. W. Rankin (W)
*Central Piedmont
H. Bell (W)
*Shelby quadrangle (monazite)
W. C. Overstreet (W)
*Geologic setting of the Spruce Pine pegmatite district (mica, feldspar)
D. A. Brobst (D)
Pegmatites of the Spruce Pine and Franklin-Sylva districts
F. G. Lesure (Knoxville, Tenn.)
*Swain County copper district
G. H. Espenshade (W)
Utility of public water supplies
K. F. Harris (q, Raleigh, N.C.)
Salt-water intrusion in coastal streams
J. C. Chemerys (q, Raleigh, N.C.)
Chemical and physical quality characteristics of public water supplies
K. F. Harris (q, Raleigh, N.C.)
Stream-channel characteristics
W. E. Forrest (s, Raleigh, N.C.)
Stream sanitation and water supply
G. C. Goddard (s, Raleigh, N.C.)
Flood gaging
H. G. Hinson (s, Raleigh, N.C.)
Flood-frequency studies
W. E. Forrest (s, Raleigh, N.C.)
Interpretation of data (surface water)
G. C. Goddard (s, Raleigh, N.C.)
Stratigraphy of the Trent Marl and related units
P. M. Brown (g, Raleigh, N.C.)
Diagenesis and hydrologic history of the Tertiary limestone of North Carolina
H. E. LeGrand (w, W)
Northwestern North Carolina (ground water)
P. M. Brown (g, Raleigh, N.C.)
Asheville area (ground water)
P. M. Brown (g, Raleigh, N.C.)
Blue Ridge Parkway construction sites (ground water)
J. O. Kimrey (g, Raleigh, N.C.)
Cape Hatteras National Park (ground water)
G. W. Lutz (g, Raleigh, N.C.)
Cape Hatteras National Park (quality of ground water)
K. F. Harris (q, Raleigh, N.C.)
City of Cary (ground water)
P. M. Brown (g, Raleigh, N.C.)
Chowan County (ground water)
P. M. Brown (g, Raleigh, N.C.)
Craven County (ground water)
P. M. Brown (g, Raleigh, N.C.)
Durham area (ground water)
P. M. Brown (g, Raleigh, N.C.)

North Carolina—Continued
Fredericksburg and Richmond National Parks (ground water)
G. G. Wyrick (g, Raleigh, N.C.)
Hartford-Elizabeth City area (ground water)
P. M. Brown (g, Raleigh, N.C.)
Marion area (ground water)
P. M. Brown (g, Raleigh, N.C.)
Martin County (ground water)
G. G. Wyrick (g, Raleigh, N.C.)
Monroe area (ground water)
E. O. Floyd (g, Raleigh, N.C.)
Surface-water resources, Neuse River headwaters
W. E. Forrest (s, Raleigh, N.C.)
Murphy area (ground water)
P. M. Brown (g, Raleigh, N.C.)
Plymouth area (ground water)
H. Peek (g, Raleigh, N.C.)
Raleigh area (ground water)
J. O. Kimrey (g, Raleigh, N.C.)
Southport area (ground water)
P. M. Brown (g, Raleigh, N.C.)
Waynesville area (ground water)
P. M. Brown (g, Raleigh, N.C.)

North Dakota:
Chemical and physical properties of the Pierre Shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota and South Dakota
C. A. Sandberg (D)
Geology of the Williston Basin with reference to the disposal of high-level radioactive wastes
C. A. Sandberg (D)
Peak discharges from small areas
O. A. Crosby (s, Bismarck, N. Dak.)
Low-flow frequency, Red River of the North
H. M. Erskine (s, Bismarck, N. Dak.)
Hydrology of prairie potholes
W. S. Eisenlohr (h, D)
Special streamflow measurements of the Souris River at Minot
E. Bradley (g, Grand Forks, N. Dak.)
Barnes County (ground water)
Q. F. Paulson (g, Grand Forks, N. Dak.)
Burleigh County (ground water)
Jack Kume (g, Grand Forks, N. Dak.)
Glacial valleys in Divide, Williams, and McKenzie Counties (ground water)
E. Bradley (g, Grand Forks, N. Dak.)
Kidder County (ground water)
E. Bradley (g, Grand Forks, N. Dak.)
Stutsman County (ground water)
C. J. Huxel (g, Grand Forks, N. Dak.)
Traill County (ground water)
H. M. Jensen (g, Grand Forks, N. Dak.)
Bowbells area (ground water)
H. M. Jensen (g, Grand Forks, N. Dak.)
Cheyenne and Standing Rock Indian Reservations (ground water)
J. E. Powell (g, Huron, S. Dak.)
Devils Lake area (ground water)
P. D. Akin (g, Grand Forks, N. Dak.)

North Dakota—Continued
- Chemical quality of surface waters, Devils Lake area
  - P. G. Rosene (q, Lincoln, Nebr.)
- Chemical quality of surface waters and sedimentation in the Heart River drainage basin
  - M. A. Maderak (q, Lincoln, Nebr.)
- Heimdal Valley, Wells, Eddy, and Foster Counties (ground water)
  - E. Bradley (g, Grand Forks, N. Dak.)
- Lakota area (ground water)
  - E. Bradley (g, Grand Forks, N. Dak.)
- Reynolds area (ground water)
  - H. M. Jensen (g, Grand Forks, N. Dak.)
- Strasburg-Linton area (ground water)
  - P. Randich (g, Grand Forks, N. Dak.)

Ohio:
- Seismic survey for buried valleys
  - R. M. Hazlewood (D)
- Geology and coal resources of Belmont County
  - H. L. Berryhill, Jr. (D)
- Aerial radiological monitoring surveys, Columbus
  - R. G. Bates (W)
- Low flow and storage requirements
  - W. P. Cross (s, Columbus, Ohio)
- Glacial mapping in Ohio
  - G. W. White (g, Columbus, Ohio)
- Northeastern Ohio (ground water)
  - J. L. Rau (g, Columbus, Ohio)
- Mapping of buried valleys
  - S. E. Norris (g, Columbus, Ohio)
- Fairfield County (ground water)
  - G. D. Dove (g, Columbus, Ohio)
- Geauga County (ground water)
  - J. Baker (g, Columbus, Ohio)
- Portage County (ground water)
  - J. D. Winslow (g, Columbus, Ohio)
- Canton area (ground water)
  - J. D. Winslow (g, Columbus, Ohio)
- Dayton area (ground water)
  - S. E. Norris (g, Columbus, Ohio)
- Hamilton-Middletown area (ground water)
  - S. E. Norris (g, Columbus, Ohio)
- Miami River basin (ground water)
  - A. M. Spieker (g, Columbus, Ohio)
- Venice area (ground water)
  - A. M. Spieker (g, Columbus, Ohio)

Oklahoma:
- Trace elements in rocks of Pennsylvanian age, Oklahoma, Kansas, Missouri (uranium, phosphate)
  - W. Danilchik (Quetta, Pakistan)
- Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
  - E. T. McKnight (W)
- Permian stratigraphy of northern Texas and southern Oklahoma
  - E. J. McKay (D)
- Anadarko Basin, Oklahoma and Texas (oil and gas)
  - W. L. Adkison (Lawrence, Kans.)
- Geology of the Anadarko Basin with reference to disposal of high-level radioactive wastes
  - M. MacLachlan (D)
- McAlester Basin (oil and gas)
  - S. E. Frezon (D)
- *Ft. Smith district, Arkansas and Oklahoma (coal and gas)
  - T. A. Hendricks (D)

Oklahoma—Continued
- Aeromagnetic interpretation, Wichita Mountains system
  - A. Griscom (W)
- Land-use evaluation
  - F. W. Kennon (h, Oklahoma City, Okla.)
- Thickness of the fresh ground-water zone
  - D. L. Hart (g, Norman, Okla.)
- Municipal and industrial water supplies
  - A. R. Leonard (g, Norman, Okla.)
- Low-flow frequency analysis
  - W. F. Busch (s, Harrisburg, Pa.)
- Ground water in the Arbuckle Limestone in the northeastern Arbuckle Mountains
  - I. W. Marine (g, Norman, Okla.)
- Beaver County (ground water)
  - I. W. Marine (g, Norman, Okla.)
- Garber Sandstone in Cleveland and Wellington Counties (ground water)
  - A. R. Leonard (g, Norman, Okla.)
- Woodward County (ground water)
  - B. L. Stacy (g, Norman, Okla.)
- Water-quality conservation in the Arkansas and Red River basins
  - P. E. Ward (g, Norman, Okla.)
- Upper Arkansas River basin (quality of surface waters)
  - R. P. Orth (q, Oklahoma City, Okla.)
- Arkansas and Verdigris River valleys (ground water)
  - H. H. Tanaka (g, Norman, Okla.)
- Quality of water in the Arkansas River at the Arkansas-Oklahome State line
  - J. J. Murphy (q, Oklahoma City, Okla.)
- Little River basin (quality of surface water)
  - G. Bednar (q, Oklahoma City, Okla.)
- Water quality reconnaissance of Verdigris River basin above Caney River
  - R. P. Orth (q, Oklahoma City, Okla.)
- Washita River basin (quality of surface water)
  - J. J. Murphy (q, Oklahoma City, Okla.)
- Beaver Creek basin (surface water)
  - L. L. Laine (s, Oklahoma City, Okla.)
- Clinton-Sherman Air Force Base (ground water)
  - A. R. Leonard (g, Norman, Okla.)
- Cottonwood Creek basin (surface water)
  - L. L. Laine (s, Oklahoma City, Okla.)
- Elk Creek basin (surface water)
  - A. O. Westfall (s, Oklahoma City, Okla.)
- Otter Creek basin (surface water)
  - A. O. Westfall (s, Oklahoma City, Okla.)
- Otter and Elk Creek basins (ground water)
  - J. R. Hollowell (g, Norman, Okla.)
- Ground water in the Rush Springs Sandstone
  - H. H. Tanaka (g, Norman, Okla.)

Oregon:
- Oregon State geologic map
  - G. W. Walker (M)
- Cenozoic mollusks
  - E. J. Moore (M)
- Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
  - W. C. Smith (M)
- *Canyon City 2-degree quadrangle
  - T. P. Thayer (W)
- *John Day area (chromite)
  - T. P. Thayer (W)

Oregon—Continued
Lateritic nickel deposits of the Klamath Mountains, Oregon and California
P. E. Hotz (M)
*Monument quadrangle
R. E. Wilcox (D)
*Newport Embayment
P. D. Snavely, Jr. (M)
*Ochoco Reservation, Lookout Mountain, Eagle Rock, and Post quadrangles (quicksilver)
A. C. Waters (Baltimore, Md.)
*Portland industrial area, Oregon and Washington (urban geology)
D. E. Trimble (D)
*Quartzburg district (cobalt)
J. S. Vhay (Spokane, Wash.)
Pacific Northwest geophysical studies
W. E. Davis (M)
Aeromagnetic and gravity studies in west-central Oregon
R. W. Bromery (W)
Aerial radiological monitoring surveys, Hanford area
R. G. Schmidt (W)
An appraisal of water quality and water-quality problems of certain streams in Oregon
R. J. Madison (q, Portland, Oreg.)
Lower Columbia River Basin (quality of surface water)
J. F. Santos (q, Portland, Oreg.)
Suspended sediment production of forested watersheds
R. C. Williams (q, Portland, Oreg.)
Columbia River Basalt hydrology
R. C. Newcomb (g, Portland, Oreg.)
Artificial recharge of basalt aquifers at the Dalles
B. L. Foxworthy (g, Portland, Oreg.)
Eola and Amity Hills (ground water)
D. Price (g, Portland, Oreg.)
Florence area (ground water)
E. R. Hampton (g, Portland, Oreg.)
Fort Rock basin (ground water)
E. R. Hampton (g, Portland, Oreg.)
French Prairie (ground water)
D. Price (g, Portland, Oreg.)
East Portland area (ground water)
B. L. Foxworthy (g, Portland, Oreg.)
West Portland area (ground water)
S. G. Brown (g, Portland, Oreg.)
Raft River basin water records (ground water)
M. J. Mundorff (g, Portland, Oreg.)
Artificial recharge of basalt acquifers at Salem Heights
B. L. Foxworthy (g, Portland, Oreg.)
Tumalo District, Deschutes County (ground water)
B. L. Foxworthy (g, Portland, Oreg.)
Northern Willamette valley east of Pudding River (ground water)
E. R. Hampton (g, Portland, Oreg.)

Pennsylvania:
*Devonian stratigraphy of Pennsylvania
G. W. Colton (W)
*Bituminous coal resources
E. D. Patterson (W)
*Geology in the vicinity of anthracite-mine drainage projects
J. F. Robertson (Mt. Carmel, Pa.)
*Flood control, Anthracite region
M. J. Bergin (Mt. Carmel, Pa.)

Pennsylvania—Continued
*Southern anthracite field
G. H. Wood, Jr. (W)
*Western Middle anthracite field
H. H. Arndt (W)
Washington County (coal)
H. Berryhill, Jr. (D)
Selected studies of uranium deposits
H. Klemic (Bowling Green, Ky.)
*Leighton quadrangle (uranium)
H. Klemic (Bowling Green, Ky.)
*Glacial geology of the Elmira-Williamsport area, New York and Pennsylvania
C. S. Denny (W)
*Lower Delaware River basin, New Jersey and Pennsylvania
J. P. Owens (W)
*Middle Delaware River basin, New Jersey and Pennsylvania
A. A. Drake, Jr. (W)
*Investigations of the Lower Cambrian of the Philadelphia district
J. H. Wallace (W)
Correlation of aeromagnetic studies and areal geology, Triassic area
R. W. Bromery (W)
Aerial radiological monitoring surveys
R. W. Johnson (Knoxville, Tenn.)
Mining hydrology
W. T. Stuart (g, W)
Chemical quality of water, Statewide
D. McCartney (q, Philadelphia, Pa.)
Chemical quality of water, Allegheny River basin
D. McCartney (q, Philadelphia, Pa.)
Hydrology and sedimentation of Bixler Run watershed
J. R. George (q, Harrisburg, Pa.)
Sedimentation in the Conestoga Creek watershed
J. R. George (q, Harrisburg, Pa.)
Hydrology and sedimentation of Corey Creek and Elk Run watersheds
J. R. George (q, Harrisburg, Pa.)
Chemical characteristics of Delaware River water
D. McCartney (q, Philadelphia, Pa.)
Quality of water, Delaware River, Trenton, New Jersey
L. T. McCarthy, Jr. (q, Philadelphia, Pa.)
Salinity of the Delaware Estuary
W. B. Keighton (q, Philadelphia, Pa.)
Dissolved-solids transported by the Delaware River
W. B. Keighton (q, Philadelphia, Pa.)
Quality of water, Lehigh River basin
W. B. Keighton (q, Philadelphia, Pa.)
Potomac River basin (ground water)
P. M. Johnston (g, W)
Chemical quality of Schuylkill River basin
M. J. McGonigle (q, Philadelphia, Pa.)
Chemical character of the Susquehanna River at Harrisburg
P. W. Anderson (q, Philadelphia, Pa.)
Chemical quality, West Branch Susquehanna River
E. F. McCarren (q, Philadelphia, Pa.)
Chemical quality, West Branch Susquehanna River near Curwensville (a reconnaissance study)
E. F. McCarren (q, Philadelphia, Pa.)
Brunswick Formation (ground water)
S. M. Longwill (g, Harrisburg, Pa.)

Pennsylvania—Continued
Hydrology of limestones in the Lebanon Valley
H. Meisler (g, Harrisburg, Pa.)
Martinsburg Shale (ground water)
L. D. Carswell (g, Harrisburg, Pa.)
Mercer and Neshannock quadrangles (ground water)
C. W. Poth (g, Harrisburg, Pa.)
New Oxford Formation (ground water)
P. R. Wood (g, Harrisburg, Pa.)
Red Clay Valley (ground water)
D. H. Boggess (g, Newark, Del.)

Rhode Island:
*Ashaway quadrangle, Rhode Island and Connecticut; bedrock geologic mapping
T. G. Feininger (Boston, Mass.)
*Ashaway and Watch Hills quadrangles, Connecticut and Rhode Island; surficial geologic mapping
J. P. Schafer (Boston, Mass.)
*Carolina and Quonochontaug quadrangle; surficial geologic mapping
J. P. Schafer (Boston, Mass.)
*Chepachet, Crompton, and Tiverton quadrangles; bedrock geologic mapping
A. W. Quinn (Providence, R.I.)
*Conventry Center, Kingston, Newport, and Prudence Island quadrangles; bedrock geologic mapping
G. E. Moore, Jr. (Columbus, Ohio)
*Thompson quadrangle, Connecticut and Rhode Island
P. M. Hanshaw and H. R. Dickson (Boston, Mass.)
*Voluntown quadrangle, Rhode Island and Connecticut
T. G. Feininger (Boston, Mass.)
*Watch Hill quadrangle, Connecticut and Rhode Island; bedrock geologic mapping
G. E. Moore, Jr. (Columbus, Ohio)
*Wickford quadrangle; bedrock geologic mapping
R. B. Williams (Lawrence, Kans.)
Temperature of selected surface waters
F. H. Pauszek (q, Albany, N.Y.)
Stream-temperature records
C. E. Knox (s, Boston, Mass.)
Ashaway quadrangle (ground water)
K. E. Johnson (g, Providence, R.I.)
Chepachet quadrangle (ground water)
K. E. Johnson (g, Providence, R.I.)
Oneco quadrangle (ground water)
K. E. Johnson (g, Providence, R.I.)
Upper Pawcatuck basin (ground water)
W. B. Allen (g, Providence, R.I.)
Potowomut-Wickford area (ground water)
W. B. Allen (g, Providence, R.I.)
Watch Hill quadrangle (ground water)
K. E. Johnson (g, Providence, R.I.)

South Carolina:
Crystalline rocks
W. C. Overstreet (W)
Aerial radiological monitoring surveys, Savannah River Plant, Georgia and South Carolina
R. G. Schmidt (W)
Analyses of streamflow charactersitics
A. E. Johnson (s, Columbia, S.C.)
Compilation of streamflow records
A. E. Johnson (s, Columbia, S.C.)
Low-flow gaging
A. E. Johnson (s, Columbia, S.C.)

South Carolina—Continued
Flood-frequency studies
F. H. Wagener (s, Columbia, S.C.)
Drainage-area determinations
W. M. Bloxham (s, Columbia, S.C.)
Flood-plain aquifers
G. E. Siple (g, Columbia, S.C.)
Artesian water in Tertiary limestones in Florida, southern Georgia and adjacent parts of Alabama and South Carolina
V. T. Stringfield (w, W)
Stratigraphy of the Trent Marl and related units
P. M. Brown (g, Raleigh, N.C.)
Northeastern coastal plain (ground water)
G. E. Siple (g, Columbia, S.C.)
Salt-water intrusion in the Lower Edisto River basin
G. A. Billingsley (q, Raleigh, N.C.)
Santee River basin flood study
A. E. Johnson (s, Columbia, S.C.)
Savannah River AEC plant (ground water)
N. C. Koch (g, Columbia, S.C.)

South Dakota:
Chemical and physical properties of the Pierre Shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota, and South Dakota
C. A. Sandberg (D)
Geology of the Williston Basin with reference to the disposal of high-level radioactive wastes
C. A. Sandberg (D)
Landslide studies in the Fort Randall Reservoir area
H. D. Varnes (D)
*Southern Black Hills (pegmatite minerals)
J. J. Norton (W)
*Pegmatites of the Custer district
J. A. Redden (Blacksburg, Va.)
*Structure and metamorphism, Hill City quadrangle (pegmatite minerals)
J. C. Ratté (D)
*Southern Black Hills (uranium)
G. B. Gott (D)
Regional gravity studies in uranium geology, Black Hills area
R. M. Hazlewood (D)
*Harding County, and adjacent areas (uraniferous lignite)
G. N. Pipiringos (D)
Peak discharges from small areas
R. E. West (s, Pierre, S. Dak.)
Low-flow data collection
J. E. Wagar (s, Pierre, S. Dak.)
Hydrology of prairie potholes
W. S. Eisenlohr (h, D)
Studies of artesian wells and selected shallow aquifers
C. F. Dyer (g, Huron, S. Dak.)
Hydrology of glacial drift in selected drainage basins in eastern South Dakota
M. J. Ellis (g, Huron, S.Dak.)
Dakota Sandstone (ground water)
C. F. Dyer (g, Huron, S. Dak.)
Minor constituents in the Belle Fourche River
L. R. Petri (q, Lincoln, Nebr.)

South Dakota—Continued
- Chemical quality of surface waters and sedimentation in the Grand River drainage basin
  - P. R. Jordan (q, Lincoln, Nebr.)
- Quality of water in the Niobrara River basin
  - Cloyd H. Scott (q, Lincoln, Nebr.)
- Beadle County (ground water)
  - L.W. Howells (g, Huron S. Dak.)
- Cheyenne and Standing Rock Indian Reservations (ground water)
  - J. E. Powell (g, Huron, S. Dak.)
- Flandreau area (ground water)
  - J. E. Powell (g, Huron, S. Dak.)
- Pine Ridge Indian Reservation (ground water)
  - M. J. Ellis (g, Huron, S. Dak.)
- Sanborn County (ground water)
  - L. W. Howells (g, Huron, S. Dak.)
- Shadehill Reservoir area (ground water)
  - J. E. Powell (g, Huron, S. Dak.)

Tennessee:
- Central eastern Tennessee geophysical studies
  - R. W. Johnson (Knoxville, Tenn.)
- Aerial radiological monitoring surveys, Oak Ridge National Laboratory
  - R. G. Bates (W)
- Origin and depositional control of some Tennessee and Virginia zinc deposits
  - H. Wedow, Jr. (Knoxville, Tenn.)
- Clinton iron ores of the southern Appalachians
  - R. P. Sheldon (D)
- Massive sulfide deposits of the Ducktown district, Tennessee, and adjacent areas (copper, iron, sulfur)
  - R. M. Hernon (D)
- *East Tennessee zinc studies
  - A. L. Brokaw (D)
- Ivydell, Pioneer, Jellico West, and Ketchen quadrangles (coal)
  - K. J. Englund (W)
- *Geology of the southern Appalachin folded belt, Kentucky, Tennessee, and Virginia
  - L. D. Harris(W)
- *Great Smoky Mountains, Tennessee and North Carolina
  - J. B. Hadley (D)
- *Knoxville and vicinity (urban geology)
  - J. M. Cattermole (Columbia, Ky.)
- *Mount Rogers area, Virginia, North Carolina, and Tennessee
  - D. W. Rankin (W)
- Bridge-site studies (surface water)
  - I. J. Hickenlooper (s, Chattanooga, Tenn.)
- Flood-frequency analysis
  - W. J. Randolph (s, Chattanooga, Tenn.)
- Low-flow studies
  - J. S. Cragwall, Jr. (s, Chattanooga, Tenn.)
- Flood profiles, Chattanooga Creek
  - A. M. F. Johnson (s, Chattanooga, Tenn.)
- Large springs of eastern Tennessee
  - P. C. Sun (g, Nashville, Tenn.)
- Western Tennessee (ground water)
  - G. K. Moore (g, Nashville, Tenn.)
- Dover area (ground water)
  - M. V. Marcher (g, Nashville, Tenn.)
- Germantown-Collierville area (ground water)
  - P. C. Sun (g, Nashville, Tenn.)

Tennessee—Continued
- Highland Rim Plateau (ground water)
  - M. V. Marcher (g, Nashville, Tenn.)
- Madison County (ground water)
  - D. J. Nyman (g, Nashville, Tenn.)
- Memphis area (ground water)
  - P. C. Sun (g, Nashville, Tenn.)

Texas:
- Aerial radiological monitoring surveys, Fort Worth
  - J. A. Pitkin (W)
- Permian stratigraphy of northern Texas and southern Oklahoma
  - E. J. McKay (D)
- Anadarko Basin, Oklahoma and Texas (oil and gas)
  - W. L. Adkison (Lawrence, Kans.)
- *Texas coastal-plain geophysical and geological studies
  - D. H. Eargle (Austin, Tex.)
- Mineralogy of uranium-bearing rocks in Karnes and Duval Counties
  - A. D. Weeks (W)
- *Del Rio area
  - V. L. Freeman (D)
- *Franklin Mountains, New Mexico and Texas (petroleum)
  - R. L. Harbour (D)
- *Sierre Blanca area
  - J. F. Smith, Jr. (D)
- *Sierra Diablo region
  - P. B. King (M)
- Terrestrial impact structures, Sierre Madera
  - E. M. Shoemaker (M)
- *Wayland quadrangle (oil and gas investigations)
  - D. A. Myers (D)
- Flood-frequency studies
  - W. H. Goines (s, Austin, Tex.)
- Low-flow investigations
  - W. H. Goines (s, Austin, Tex.)
- Drainage-area determinations
  - P. H. Holland (s, Austin, Tex.)
- Special flood and hydrologic investigations
  - W. H. Goines (s, Austin, Tex.)
- Special hydrologic studies
  - W. B. Mills (s, Austin, Tex.)
- Reconnaissance sediment investigations
  - L. S. Hughes (q, Austin, Tex.)
- Chemical composition of surface waters
  - L. S. Hughes (q, Austin, Tex.)
- Reconnaissance study of the chemical quality of streams
  - L. S. Hughes (q, Austin, Tex.)
- Chemical quality of surface waters of the Brazos River basin
  - L. S. Hughes (q, Austin, Tex.)
- Hydrologic investigations, small watersheds, Trinity, Brazos, Colorado, and San Antonio Rivers basins
  - W. H. Goines (s, Austin, Tex.)
- Hydrologic effect of small reservoirs, Honey Creek
  - F. W. Kennon (h, Oklahoma City, Okla.)
- Sedimentation in the upper Trinity River basin
  - C. H. Hembree (q, Austin, Tex.)
- Escondido Creek—Trap efficiency study
  - C. H. Hembree (q, Austin, Tex.)
- Sources of salinity in the upper Brazos River basin
  - R. C. Baker (g, Austin, Tex.)
- High Plains north of the Canadian River (ground water)
  - W. H. Alexander (g, Austin, Tex.)

Texas—Continued
Carson and adjoining counties (ground water)
G. McAdoo (g, Austin, Tex.)
El Paso area (ground water)
M. E. Davis (g, Austin, Tex.)
Galveston area (ground water)
R. B. Anders (g, Austin, Tex.)
Haskell and Knox Counties (ground water)
W. Ogilbee (g, Austin, Tex.)
Hardin County ground water)
E. T. Baker, Jr. (g, Austin, Tex).
Houston district (ground water)
R. B. Anders (g, Austin, Tex.)
Northern Jim Wells County and adjacent areas (ground water)
C. C. Mason (g, Austin, Tex.)
Refugio County (ground water)
C. C. Mason (g, Austin, Tex.)
Upper and lower Rio Grande basins, Brazos, Red, and Gulf Coast basins (ground water)
L. A. Wood (g, Austin, Tex.)
Middle Rio Grande basin, Colorado, Trinity, and Sabine River basins (ground water)
R. C. Peckham (g, Austin, Tex.)
San Antonio area (ground water)
S. Garza (g, Austin, Tex.)

Utah:
General geology:
Upper Cretaceous stratigraphy, northwestern Colorado and northeastern Utah
A. D. Zapp (D)
Tuffs of the Green River Formation
R. L. Griggs (D)
*Northern Bonneville Basin
J. S. Williams (Provo, Utah)
*Confusion Range
R. K. Hose (M)
*Lehi quadrangle
M. D. Crittenden, Jr. (M)
*Little Cottonwood area
G. M. Richmond (D)
*Park City area
M. D. Crittenden, Jr. (M)
*Promontory Point
R. B. Morrison (D)
*Strawberry Valley and Wasatch Mountains
A. A. Baker (W)
*Utah Valley, south half
H. J. Bissell (Provo, Utah)
Engineering geology and geophysical studies:
*Geologic factors related to coal-mine bumps
F. W. Osterwald (D)
*Upper Green River valley (construction-site planning)
W. R. Hansen (D)
*Surficial geology of the Oak City area
D. J. Varnes (D)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Mineral resources:
L. S. Hilpert (Salt Lake City, Utah)
Geochemical halos of mineral deposits, Utah and Nevada
R. L. Erickson (D)
Colorado Plateau botanical-prospecting studies
F. J. Kleinhampl (M)

Utah—Continued
Mineral resources—Continued
*Marysvale district (alunite)
R. L. Parker (D)
*San Francisco Mountains (base metals, tungsten)
D. M. Lemmon (M)
*Cedar Mountain quadrangle, Iron County (coal)
P. Averitt (D)
Hurricane fault, southwestern Utah (coal)
P. Averitt (D)
*Southern Kolob Terrace coal field
W. B. Cashion (D)
*Fuels potential of the Navajo Reservation, Arizona and Utah
R. B. O'Sullivan (D)
*Regional geologic setting of the Bingham Canyon district (copper)
R. J. Roberts (M)
*Thomas and Dugway Ranges (fluorspar, beryllium)
M. H. Staatz (D)
*Alta quadrangle (lead, silver, phosphate rock)
M. D. Crittenden, Jr. (M)
*East Tintic lead-zinc district, including geochemical studies
H. T. Morris (M)
*Uinta Basin oil shale
W. B. Cashion (D)
Stratigraphy and resources of the Phosphoria and Park City Formations in Utah and Nevada (phosphate, minor elements)
K. M. Tagg (M)
*Wheeler Peak and Garrison quadrangles, Snake Range, Nevada and Utah (tungsten, beryllium)
D. H. Whitebread (M)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Relative concentrations of chemical elements in different rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (M)
San Rafael Group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (W)
Stratigraphic studies, Colorado Plateau (Uranium, vanadium)
L. C. Craig (D)
Lithologic studies, Colorado Plateau
R. A. Cadigan (D)
Clay studies, Colorado Plateau
L. G. Schultz (D)
*Abajo Mountains (uranium, vanadium)
I. J. Witkind (D)
*Circle Cliffs area (uranium)
E. S. Davidson (Tucson, Ariz.)
*Deer Flat area, White Canyon district (uranium, copper)
T. L. Finnell (D)
*Elk Ridge area (uranium)
R. Q. Lewis (Columbia, Ky.)

Utah—Continued
Mineral resouces—Continued
*La Sal area, Utah and Colorado (uranium, vanadium)
W. D. Carter (Santiago, Chile)
*Lisbon Valley area, Utah and Colorado (uranium, vanadium, copper)
G. W. Weir (Berea, Ky.)
*Moab-Interriver area, east-central Utah (uranium)
E. N. Hinrichs (D)
*Orange Cliffs area (uranium)
F. A. McKeown (D)
*Sage Plain area (uranium, vanadium)
L. C. Huff (D)
Uranium ore controls of the San Rafael Swell
C. C. Hawley (D)
*White Canyon area (uranium, copper)
R. E. Thaden (Columbia, Ky.)
Western oxidized-zinc deposits
A. V. Heyl (W)
Water resources:
Flood gaging
V. K. Berwick (s, Salt Lake City, Utah)
Study of the mechanics of hillslope erosion
S. A. Schumm (h, D)
Piping, an erosional phenomenon in certain silty soils of arid and semi-arid regions
G. G. Parker, R. C. Miller and I. S. McQueen (h, D)
Pumping districts of southern Utah (ground water)
G. W. Sandberg (g, Salt Lake City, Utah)
Dissolved-mineral contributions to Great Salt Lake
R. H. Langford (q, Salt Lake City, Utah)
Dinosaur National Monument (ground water)
R. E. Smith (g, Salt Lake City, Utah)
Jordan Valley (ground water)
I. W. Marine (g, Salt Lake City, Utah)
Pavant Valley (ground water)
R .W. Mower (g, Salt Lake City, Utah)
Price area (ground water)
H. D. Goode (g, Salt Lake City, Utah)
Sevier Desert (ground water)
R. W. Mower (g, Salt Lake City, Utah)
Central Sevier Valley (ground water)
R. A. Young (g, Salt Lake City, Utah)
Upper Servier Valley (ground water)
R. A. Young (g, Salt Lake City, Utah)
East Shore area (ground water)
R. E. Smith (g, Salt Lake City, Utah)
Tooele Valley (ground water)
J. S. Gates (g, Salt Lake City, Utah)
Uinta Basin (ground water)
H. D. Goode (g, Salt Lake City, Utah)
Northern Utah Valley (ground water)
S. Subitzky (g, Salt Lake City, Utah)
Weber Basin (ground water)
J. H. Feth (g, Salt Lake City, Utah)
Evaluation of sediment barrier on Sheep Creek, Paria River basin, near Tropic
G. C. Lusby (h, D)

Vermont:
*Rowe and Heath quadrangles, Massachusetts and Vermont
A. H. Chidester (D) and J. H. Hartshorn (Boston, Mass.)
*Talc and asbestos deposits of north-central Vermont
W. M. Cady (D)

Virginia:
*Potomac Basin studies, Virginia and West Virginia
J. T. Hack (W)
*Geology of the southern Appalachian folded belt, Kentucky, Tennessee, and Virginia
L. D. Harris (W)
*Mount Rogers area, Virginia, North Carolina, and Tennessee
D. W. Rankin (W)
Origin and depositional control of some Tennessee and Virginia zinc deposits
H. Wedow, Jr. (Knoxville, Tenn.)
Massive sulfide deposits of the Ducktown district, Tennessee, and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)
*Big Stone Gap district (coal, oil, and gas)
R. L. Miller (W)
Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
S. K. Neuschel (W)
*Herndon quadrangle (construction-site planning)
R. E. Eggleton (D)
Engineering geology, Washington metropolitan area
H. W. Coulter (W)
Flood investigations
C. W. Lingham (s, Charlottesville, Va.)
The hydraulic geometry of a small tidal estuary
L. B. Leopold (w, W)
Hydrologic and hydraulic studies
C. W. Lingham (s, Charlottesville, Va.)
Flood hydrology, Fairfax County and Alexandria City
D. G. Anderson (s, Charlottesville, Va.)
Potomac River basin (ground water)
P. M. Johnson (g, W)

Washington:
Pacific Northwest geophysical studies
W. E. Davis (M)
Geophysical studies, northwestern Washington
W. T. Kinoshita (M)
Gravity survey of western Washington
D. J. Stuart (D)
Aerial radiological monitoring surveys, Hanford
R. G. Schmidt (W)
Eastern Washington clay studies
J. W. Hosterman (W)
*Bald Knob quadrangle
M. H. Staatz (D)
*Bodie Mountain quadrangle
R. C. Pearson (D)
*Chewelah area (magnesite)
I. Campbell (San Francisco, Calif.)
*Glacier Peak quadrangle
D. F. Crowder (M)
*Grays Harbor basin (oil and gas)
H. D. Gower (M)
*Greenacres quadrangle, Washington and Idaho (high-alumina clays)
P. L. Weis (Spokane, Wash.)
*Holden and Lucerne quadrangles, northern Cascade Mountains (copper)
F. W. Cater (D)
*Hunters quadrangle (magnesite, tungsten, base metals, barite)
A. B. Campbell (D)

Washington—Continued
Maple Valley, Hobart and Cumberland quadrangles, King County (coal)
J. D. Vine (M)
*Metaline lead-zinc district
M. G. Dings (D)
*Mt. Spokane quadrangle, Washington and Idaho (uranium)
A. E. Weissenborn (Spokane, Wash.)
*Eastern Olympic Peninsula
W. M. Cady (D)
*Northern Olympic Peninsula
R. D. Brown, Jr. (M)
*Portland industrial area, Oregon and Washington
D. E. Trimble (D)
*Puget Sound Basin (urban geology)
D. R. Crandell (D)
*Republic quadrangle
R. L. Parker (D)
Engineering geologic studies of Seattle
D. R. Mullineaux (D)
**Geologic mapping of the Spokane-Wallace region, Washington and Idaho
A. B. Griggs (M)
*Stevens County lead-zinc district
R. G. Yates (M)
*Turtle Lake quadrangle, (uranium)
G. E. Becraft (D)
*Wilmont Creek quadrangle
G. E. Becraft (D)
Glacialogical research
M. F. Meier (h, Tacoma, Wash.)
Geomorphology of glacier streams
R. K. Fahnestock (h, Fort Collins, Colo.)
Cedar River basin (surface water)
F. M. Veatch (s, Tacoma, Wash.)
Chelalis River basin (surface water)
E. G. Bailey (s, Tacoma, Wash.)
Columbia River Basalt, hydrology
R. C. Newcomb (g, Portland, Oreg.)
Artificial recharge of basalt aquifers, Walla Walla
A. A. Garrett (g, Tacoma, Wash.)
Relationship of ground-water storage and streamflow, Columbia River basin
A. A. Garrett (g, Tacoma, Wash.)
Columbia Basin Irrigation Project (ground water)
J. W. Bingham (g, Tacoma, Wash.)
Lower Columbia River basin (quality of surface water)
J. F. Santos (q, Portland, Oreg.)
Hydrology of Lower Flett Creek basin
F. M. Veatch (s, Tacoma, Wash.)
Grant, Adams, and Franklin Counties (ground water)
M. J. Grolier (g, Tacoma, Wash.)
Southwest King County (ground water)
K. L. Walters (g, Tacoma, Wash.)
Central Pierce County (ground water)
K. L. Walters (g, Tacoma, Wash.)
Thurston County (ground water)
E. F. Wallace (g, Tacoma, Wash.)
Whitman County (ground water)
K. L. Walters (g, Tacoma, Wash.)
Whitman National Monument (ground water)
J. W. Bingham (g, Tacoma, Wash.)

West Virginia:
*Potomac Basin studies, Virginia and West Virginia
J. T. Hack (W)
General hydrology
W. L. Doll (s, Charleston, W. Va.)
Potomac River basin (ground water)
P. M. Johnston (g, W)
Ohio County (ground water)
G. Meyer (g, Morgantown, W. Va.)
Lower Kanawha River valley (ground water)
B. M. Wilmoth (g, Morgantown, W. Va.)
Teays Valley (ground water)
E. C. Rhodehamel (g, Morgantown, W. Va.)

Wisconsin:
Geophysical studies in the Lake Superior region
G. D. Bath (M)
*Florence County (iron)
C. E. Dutton (Madison, Wis.)
Correlation of aeromagnetic studies and areal geology, Florence County
E. R. King (W)
*Wisconsin zinc-lead mining district
J. W. Whitlow (W)
*Stratigraphy of the lead-zinc district near Dubuque
J. W. Whitlow (W)
Geochemical survey of the Driftless Area
H. T. Shacklette (D)
Low-flow frequency analyses
K. B. Young (s, Madison, Wisc.)
Regional flood frequency
D. W. Ericson (s, Madison, Wis.)
Northwestern Wisconsin (ground water)
R. W. Ryling (g, Madison, Wis.)
Dane County (ground water)
D. R. Cline (g, Madison, Wis.)
Green Bay area (ground water)
D. B. Knowles (g, Madison, Wis.)
Milwaukee area (ground water)
R. W. Ryling (g, Madison, Wis.)
Little Plover River basin (ground water)
D. B. Knowles (g, Madison, Wis.)
Portage County (ground water)
C. L. R. Holt (g, Madison, Wis.)
Rock County (ground water)
E. F. LeRoux (g, Madison, Wis.)
Waupaca County (ground water)
C. F. Berkstresser (g, Madison, Wis.)
Waushara County (ground water)
W. K. Summers (g, Madison, Wis.)

Wyoming:
General geology and engineering geology:
Geology and paleolimnology of the Green River Formation
W. H. Bradley (W)
Mineralogy and geochemistry of the Green River Formation
C. Milton (W)
Tuffs of the Green River Formation
R. L. Griggs (D)
Upper Cretaceous stratigraphy
A. D. Zapp
Chemical and physical properties of the Pierre Shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)

Wyoming—Continued
General geology and engineering geology—Continued
Stratigraphy and paleontology of the Pierre Shale, Front Range area, Colorado and Wyoming
W. A. Cobban and G. R. Scott (D)
*Regional stratigraphic study of the Inyan Kara Group, Black Hills
W. J. Mapel (D)
Investigation of Jurassic stratigraphy, south-central Wyoming and northwestern Colorado
G. N. Pipiringos (D)
Permian stratigraphy
E. K. Maughan (D)
Pennsylvanian and Permian stratigraphy, Front Range
E. K. Maughan (D)
Chemical composition of thermal waters in Yellowstone Park
G. W. Morey (W)
*Big Piney area
S. S. Oriel (D)
*Clark Fork area
W. G. Pierce (M)
*Cokeville quadrangle
W. W. Rubey (Los Angeles, Calif.)
*Fort Hill quadrangle
S. S. Oriel (D)
*Fossil basin, southwest Wyoming
J. I. Tracey, Jr. (W)
*Geology of Grand Teton National Park
J. D. Love (Laramie, Wyo.)
*Upper Green River valley (construction-site planning)
W. R. Hansen (D)
Geology of the Powder River Basin with reference to the disposal of high-level radioactive wastes
H. Beikman (D)
Geology of the Williston Basin with reference to the disposal of high-level radioactive wastes
C. A. Sandberg (D)
*Quaternary geology of the Wind River Mountains
G. M. Richmond (D)
Mineral resources:
*Atlantic City district (iron, gold)
R. W. Bayley (M)
*Beaver Divide area (oil and gas)
F. B. Van Houten (Princeton, N.J.)
*Crowheart Butte area (oil and gas)
J. F. Murphy (D)
*Shotgun Butte (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Whalen-Wheatland area (oil and gas)
L. W. McGrew (Laramie, Wyo.)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota, and South Dakota
C. A. Sandberg (D)
Regional geology of the Wind River Basin (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Green River Formation, Sweetwater County (oil shale, salines)
W. C. Culbertson (D)
Stratigraphy and resources of Permian rocks in western Wyoming (phosphate, minor elements)
R. P. Sheldon (D)
Titaniferous black sands in Upper Cretaceous rocks
R. S. Houston (Laramie, Wyo.)

Wyoming—Continued
Mineral resources—Continued
Uranium and phosphate in the Green River Formation
W. R. Keefer (Laramie, Wyo.)
*Baggs area, Wyoming and Colorado (uranium)
G. E. Prichard (D)
*Crooks Gap area, Fremont County (uranium)
J. G. Stephens (D)
*Gas Hills district (uranium)
H. D. Zeller (D)
*Hiland–Clarkson Hills area (uranium)
E. I. Rich (M)
*Pumpkin Buttes area, Powder River Basin (uranium)
W. N. Sharp (D)
*Southern Powder River Basin (uranium)
W. N. Sharp (D)
*Red Desert area (uranium in coal)
G. N. Pipiringos (D)
*Shirley Basin area (uranium)
E. N. Harshman (D)
*Storm Hill quadrangle (uranium)
G. A. Izett (D)
Strawberry Hill quadrangle (uranium)
R. E. Davis (D)
Regional gravity studies in uranium geology, Black Hills area
R. M. Hazlewood (D)
Water resources:
Flood gaging
J. R. Carter (s, Cheyenne, Wyo.)
Bridge-site studies
J. R. Carter (s, Cheyenne, Wyo.)
Effects of exposure on slope morphology
R. F. Hadley (h, D)
Scour of river beds during high flow
L. B. Leopold (w, W)
Mining hydrology
W. T. Stuart (g, W)
Sedimentation and chemical quality of surface waters in the Bighorn River basin, Wyoming and Montana
T. F. Hanly (q, Worland, Wyo.)
Chemical quality of ground water in Johnson County
T. R. Cummings (q, Worland, Wyo.)
Quality of water in the Niobrara River basin
Cloyd H. Scott (q, Lincoln, Nebr.)
Chemical quality of ground water in Sheridan County
T. R. Cummings (q, Worland, Wyo.)
Sedimentation and chemical quality of surface waters in the Wind River Basin
T. F. Hanly (q, Worland, Wyo.)
Cheyenne area (ground water)
E. D. Gordon (g, Cheyenne, Wyo.)
Northern and western Crook County (ground water)
H. A. Whitcomb (g, Cheyenne, Wyo.)
Devils Tower National Monument (ground water)
E. D. Gordon (g, Cheyenne, Wyo.)
Glendo area, hydrologic studies
E. P. Weeks (g, Cheyenne, Wyo.)
Grand Teton National Park (ground water)
E. D. Gordon (g, Cheyenne, Wyo.)
Northern Johnson County (ground water)
R. A. McCullough (g, Cheyenne, Wyo.)
Lyman–Mountain View area (ground water)
C. J. Robinove (g, Cheyenne, Wyo.)

Wyoming—Continued
Water resources—Continued
Niobrara County (ground water)
H. A. Whitcomb (g, Cheyenne, Wyo.)
Sheridan County (ground water)
M. E. Lowry (g, Cheyenne, Wyo.)
Upper Star Valley (ground water)
M. J. Mundorff (g, Boise, Idaho)
Wheatland Flats area (ground water)
E. P. Weeks (g, Cheyenne, Wyo.)
Bridge Bay, Yellowstone National Park (ground water)
E. D. Gordon (g, Cheyenne, Wyo.)

Puerto Rico and Caribbean area:
*Geology and mineral resources of Puerto Rico
W. H. Monroe (San Juan, Puerto Rico)
Carbonate sediments, Bahama Banks
P. E. Cloud (Minneapolis, Minn.)
Recent Foraminifera, Central America
P. J. Smith (M)
Geophysical studies in Puerto Rico
A. Griscom (W)
Aerial radiological monitoring surveys
J. A. Pitkin (W)
Puerto Rico (surface water)
D. B. Bogart (s, San Juan, Puerto Rico)
Flood-inundation mapping
D. B. Bogart (s, San Juan, Puerto Rico)
Lower Tallaboa Valley, Puerto Rico (ground water)
I. G. Grossman (g, San Juan, Puerto Rico)
Use of water by industry
J. W. Crooks (q, San Juan, Puerto Rico)
Jobos area (water resources)
N. E. McClymonds (g, San Juan, Puerto Rico)
Humacao area (flood-inundation mapping)
M. A. López (s, San Juan, Puerto Rico)
Guayanilla area (water resources)
J. W. Crooks (q, San Juan, Puerto Rico)
Bayamón area (flood-inundation mapping)
M. A. López (s, San Juan, Puerto Rico)
Guantanamo Bay, Cuba (ground water)
H. Sutcliffe (g, Tallahassee, Fla.)
St. Croix, Virgin Islands (water resources)
G. E. Hendrickson (g, Christiansted, Virgin Islands of the U.S.)

Western Pacific Islands:
Cenozoic mollusks, western Pacific Islands
H. S. Ladd (W)
Cenozoic smaller Foraminifera, Pacific Ocean and islands
M. R. Todd (W)
Cenozoic gastropods and pelecypods, Pacific islands
F. S. MacNeil (M)
American Samoa (ground water)
K. J. Takasaki (g, Honolulu, Hawaii)
*Bikini and nearby atolls
H. S. Ladd (W)
*Guam
J. I. Tracey, Jr. (W)
Guam (ground water)
D. A. Davis (g, Honolulu, Hawaii)
*Ishigaki, Ryukyu Islands
H. L. Foster (W)
*Okinawa
G. Corwin (W)

Western Pacific Islands—Continued
Southern Okinawa (ground water)
D. A. Davis (g, Honolulu, Hawaii)
*Pagan Island
G. Corwin (W)
*Palau Islands
G. Corwin (W)
*Tinian
D. B. Doan (W)
*Truk
J. T. Stark (Recife, Brazil)
*Yap and Caroline Islands
C. G. Johnson (Honolulu, Hawaii)
Pacific Islands vegetation
F. R. Fosberg (W)

Antarctica:
**Reconnaissance geology of western Antarctica
E. L. Boudette (W)
*Horlick Mountains
A. B. Ford (W)
Reconnaissance geology along the Eights and Walgreen Coasts
A. A. Drake, Jr. (W)

Geologic and hydrologic investigations in other nations:
Afganistan—ground-water investigatory programming
P. E. Dennis (w, Kabul, Afganistan)
Afganistan—surface-water resources of Helmand River basin
R. H. Brigham (w, Lashkar Gah, Afganistan)
Belgium—radiohydrology
E. S. Simpson (w, Mons, Belgium)
Bolivia—mineral resources and geologic mapping (advising and training)
C. M. Tschanz (LaPaz, Bolivia)
*Brazil—iron and manganese resources, Minas Gerais
J. V. N. Dorr II (Belo Horizonte, Brazil)
*Brazil—base-metal resources
A. J. Bodenlos (Rio de Janeiro, Brazil)
Brazil—geological education
A. J. Bodenlos (Rio de Janerio, Brazil)
Brazil—education in ground-water geology and hydrology
D. J. Cederstrom (w, Rio de Janeiro, Brazil)
*Chile—mineral resources and national geologic mapping
W. D. Carter (Santiago, Chile)
Chile—ground-water investigations and hydrogeologic mapping
R. J. Dingman (w, Santiago, Chile)
**Greenland, eastern—surficial geology (construction-site planning)
W. E. Davies (W)
Indonesia
R. F. Johnson
Iran—nationwide river-basin surveys
A. F. Pendleton (w, Teheran, Iran)
**Libya—industrial minerals and national geologic map
G. H. Goudarzi (Tripoli, Libya)
Libya—nationwide ground-water investigation and pilot development
J. R. Jones (w, Benghazi, Libya)
Mexico—training in regional geologic mapping
C. T. Pierson (Mexico, D.F., Mexico)
Nepal—nationwide surface-water reconnaissance
F. M. Veatch (w, Katmandu, Nepal)

Geologic and hydrologic investigations in other nations—Con.
- Pakistan—mineral-resources development (advisory and training)
  - J. A. Reinemund (Quetta, Pakistan)
- Pakistan—hydrologic investigations related to waterlogging and salinity control
  - D. W. Greenman (w, Lahore, Pakistan)
- **Philippines—iron, chromite and nonmetallic mineral resources
  - J. F. Harrington (Manila, P.I.)
- **Saudi Arabia—national geologic map
  - G. F. Brown (Jidda, Saudi Arabia)
- Sudan—ground-water investigations Kordofan Province
  - H. G. Rodis (w, Khartoum, Sudan)
- Thailand—economic geology and mineral industry expansion (advisory)
  - L. S. Gardner (Bangkok, Thailand)
- Tunisia—ground-water investigations and hydrogeologic mapping
  - H. E. Thomas (w, Tunis, Tunisia)
- Turkey—Geological education, University of Istanbul (training)
  - Q. D. Singewald (Istanbul, Turkey)
- Turkey—nationwide surface-water investigations
  - L. J. Snell (w, Ankara, Turkey)
- United Arab Republic (Egypt)—ground-water investigation and pilot development in the Kharga Oasis
  - H. A. Waite (w, Cairo, Egypt)

Extraterrestrial studies—Lunar geology, tektites, and meteorites:
- Photogeology of the moon—stratigraphy and structure of the Kepler region
  - R. J. Hackman (W)
- Photogeology of the moon—stratigraphy and structure of the Letronne and Riphaeus Mountains regions
  - C. H. Marshall (M)

Extraterrestrial studies—Lunar geology tektites, and meteorites—Continued
- Terrane study of the moon
  - C. R. Warren (W)
- Photogeology of the moon—lunar photometry
  - W. A. Fischer (W)
- Lunar physical properties, measuring techniques
  - E. M. Shoemaker (M)
- X-ray fluorescence equipment for lunar studies
  - I. Adler (W)
- Terrestrial impact structures—Decaturville Dome, Mo.
  - D. J. Milton (M)
- Terrestrial impact structures—Meteor Crater, Ariz.
  - E. M. Shoemaker (M)
- Terrestrial impact structures—Sierra Madera, Tex.
  - E. M. Shoemaker (M)
- Shock-phase studies
  - D. J. Milton (M)
- Experimental hypervelocity impact studies
  - H. J. Moore (M)
- Impact metamorphism
  - E. C. T. Chao (W)
- Diatremes, Navajo and Hopi Indian Reservations
  - E. M. Shoemaker (M)
- Age determination of tektites
  - P. Signer (Minneapolis, Minn.)
- Chemistry of tektites
  - F. Cuttita (W)
- Mineralogy and petrology of meteorites and tektites
  - E. C. T. Chao (W)
- Thermoluminescence and mass physical properties
  - C. H. Roach (D)

TOPICAL INVESTIGATIONS

Heavy metals:
District studies:
Ferrous and ferro-alloy metals:
*Selected iron deposits of the Northeastern States
A. F. Buddington (Princeton, N.J.)
Clinton iron ores of the southern Appalachians
R. P. Sheldon (D)
*Southern Dickinson County, Michigan (iron)
R. W. Bayley (M)
*Florence County, Wisconsin (iron)
C. E. Dutton (Madison, Wis.)
*East Marquette district, Michigan (iron)
J. E. Gair (D)
*Eastern Iron County, Michigan (iron)
K. L. Wier (D)
*Iron River–Crystal Falls district, Michigan (iron)
H. L. James (Minneapolis, Minn.)
*Negaunee and Palmer quadrangles, Michigan (iron)
J. E. Gair (D)
*Cuyuna North Range, Minnesota (iron)
R. G. Schmidt (W)
Deposits of Nevada (iron)
R. G. Reeves (Alegro, Brazil)
*Atlantic City district, Wyoming (iron, gold)
R. W. Bayley (M)
*Unionville and Buffalo Mountain quadrangles, Humboldt Range, Nevada (iron, tungsten, silver, quicksilver)
R. E. Wallace (M)
Ore deposits of southwestern Montana (iron)
H. L. James (Minneapolis, Minn.)
**Klukwan iron district, Alaska
E. C. Robertson (W)
*Southeastern Aroostook County, Maine (manganese)
L. Pavlides (W)
Philipsburg area, Montana (manganese and base metals)
W. C. Prinz (W)
John Day area, Oregon (chromite)
T. P. Thayer (W)
Northern California (chromite)
F. G. Wells (W)
Lateritic nickel deposits of the Klamath Mountains, Oregon-California
P. E. Hotz (M)
*Hamme tungsten deposit, North Carolina
J. M. Parker, 3d (Raleigh, N.C.)
*Wheeler Peak and Garrison quadrangles, Snake Range, Nevada and Utah (tungsten and beryllium)
D. H. Whitebread (M)
*Osgood Mountains quadrangle, Nevada (tungsten, quicksilver)
P. E. Hotz (M)
*Bishop tungsten district, California
P. C. Bateman (M)
*Eastern Sierra tungsten area, California: Devil's Postpile (tungsten, base metals)
N. K. Huber (M)
*Geologic study of the Sierra Nevada batholith, California (tungsten, gold, base metals)
P. C. Bateman (M)
*Blackbird Mountain area, Idaho (cobalt)
J. S. Vhay (Spokane, Wash.)
*Quartzburg district, Oregon (cobalt)
J. S. Vhay (Spokane, Wash.)

Heavy metals—Continued
District studies—Continued
*Thunder Mountain niobium area, Montana and Idaho
R. L. Parker (D)
Magnet Cove niobium investigations, Arkansas
L. V. Blade (Paducah, Ky.)
Base and precious metals:
*Swain County copper district, North Carolina
G. H. Espenshade (W)
Massive sulfide deposits of the Ducktown district, Tennessee, and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)
*Michigan copper district
W. S. White (W)
Copper deposits in sandstone
C. B. Read (Albuquerque, N. Mex.)
*Bradshaw Mountains, Arizona (copper)
C. A. Anderson (W)
*Klondyke quadrangle, Arizona (copper)
F. S. Simons (D)
*Christmas quadrangle, Arizona (copper, iron)
C. R. Willden (M)
Contact-metamorphic deposits of the Little Dragoons area, Arizona (copper)
J. R. Cooper (D)
*Globe-Miami area, Arizona (copper)
D. W. Peterson (M)
*Mammoth and Benson quadrangles, Arizona (copper)
S. C. Creasey (M)
*Prescott-Paulden area, Arizona (copper)
M. H. Krieger (M)
*Twin Buttes area, Arizona (copper)
J. R. Cooper (D)
*Regional geologic setting of the Bingham Canyon district, Utah (copper)
R. J. Roberts (M)
*Regional geologic setting of the Ely district, Nevada (copper, lead, zinc)
A. L. Brokaw (D)
Structural geology of the Sierra foothills mineral belt, California (copper, zinc, gold, chromite)
L. D. Clark (M)
*Holden and Lucerne quadrangles, Northern Cascade Mountains, Washington (copper)
F. W. Cater (D)
**Southern Brooks Range, Alaska (copper, precious metals)
W. P. Brosgé (M)
*Volcanic and economic geology of the Creede caldera, Colorado (base and precious metals, fluorspar)
T. A. Steven (D)
*Lochiel and Nogales quadrangles, Arizona (lead, zinc, copper)
F. S. Simons (D)
*Silver City region, New Mexico (copper, zinc)
W. R. Jones (D)
*San Francisco Mountains, Utah (base metals, tungsten)
D. M. Lemmon (M)
*East Tintic lead-zinc district, Utah, including geochemical studies
H. T. Morris (M)
*Minturn quadrangle, Colorado (zinc, silver, copper, lead, gold)
T. S. Lovering (D)

Heavy metals—Continued
District studies—Continued
*Rico district, Colorado (lead, zinc, silver)
E. T. McKnight (W)
*Tenmile Range, including the Kokomo mining district, Colorado (base and precious metals)
A. H. Koschmann (D)
*Eureka mining district, Nevada (zinc, lead, silver, gold)
T. B. Nolan
*Boulder batholith area, Montana (base, precious, and radioactive metals)
M. R. Klepper (W)
*Antler Peak quadrangle, Nevada (base and precious metals)
R. J Roberts (M)
*East Tennessee zinc studies
A. L. Brokaw (D)
Origin and depositional control of some Tennessee and Virginia zinc deposits
H. Wedow, Jr. (Knoxville, Tenn.)
*Wisconsin zinc-lead mining district
J. W. Whitlow (W)
*Stratigraphy of the lead-zinc district near Dubuque, Iowa
J. W. Whitlow (W)
*Southeastern Missouri (lead)
T. H. Kiilsgaard (W)
Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
*Alta quadrangle, Utah (lead, silver, phosphate rock)
M. D. Crittenden, Jr. (M)
*Coeur d'Alene mining district, Idaho (lead, zinc, silver)
S. W. Hobbs (W)
Ione quadrangle, Nevada (lead, quicksilver, tungsten)
C. J. Vitaliano (Bloomington, Ind.)
*New York Butte quadrangle, California (lead-zinc)
W. C. Smith (M)
*Panamint Butte quadrangle, California, including special geochemical studies (lead-silver)
W. E. Hall (W)
*Metaline lead-zinc district, Washington
M. G. Dings (D)
*Stevens County, Washington, lead-zinc district
R. G. Yates (M)
*Mt. Diablo area, California (quicksilver, copper, gold, silver)
E. H. Pampeyan (M)
Quicksilver deposits, southwestern Alaska
E. M. MacKevett, Jr. (M)
*Ochoco Reservation, Lookout Mountain, Eagle Rock, and Post quadrangles, Oregon (quicksilver)
A. C. Waters (Baltimore, Md.)
*Nome C–1 and D–1 quadrangles, Alaska (gold)
C. L. Hummel (Bangkok, Thailand)
*Tofty placer district, Alaska (gold, tin)
D. M. Hopkins (M)
**Regional geology and mineral resources, southeastern Alaska
R. A. Loney (M)
Seward Peninsula, Alaska (tin)
P. L. Killeen (W)
*Lost River mining district, Alaska (tin, berylium)
C. L. Sainsbury (M)

Heavy metals—Continued
Commodity and topical studies:
Mineral-resource information and research
H. Kirkemo (W)
Mineral exploration, Northwestern United States
D. R. MacLaren (Spokane, Wash.)
U.S. Mineral Resource maps
W. L. Newman (W)
Resource study and appraisal of base and precious metals
A. R. Kinkel, Jr. (W)
Resource study and appraisal of ferrous and ferro-alloy metals
T. P. Thayer (W)
Origin of the Mississippi Valley type ore deposits
A. V. Heyl (W)
Alaskan metallogenic provinces
C. L. Sainsbury (M)
Resources and geochemistry of rare-earth elements
J. W. Adams (D)
Refractory-metals resources
V. C. Frylund, Jr. (W)
Western oxidized-zinc deposits
A. V. Heyl (W)
Statistical techniques in the analysis of drilling data
H. Wedow, Jr. (Knoxville, Tenn.)
Massive sulfide deposits
A. R. Kinkel, Jr. (W)
Molybdenum-rhenium resource studies
R. U. King (D)
Tantalum-niobium resources of the United States
R. L. Parker (D)
*San Juan mining area, Colorado, including detailed study of the Silverton Caldera (lead, zinc, silver, gold, copper)
R. G. Luedke (W)
*Holy Cross quadrangle, Colorado, and the Colorado mineral belt (lead, zinc, silver, copper, gold)
O. Tweto (D)
*Central City–Georgetown area, Colorado including studies of the Precambrian history of the Front Range (base, precious, and radioactive metals)
P. K. Sims (Minneapolis, Minn.)

Light metals and industrial minerals:
Resource study and appraisal, light metals and industrial minerals
J. J. Norton (W)
Titaniferous black sands in Upper Cretaceous rocks, Wyoming
R. S. Houston (Laramie, Wyo.)
*Marysvale district, Utah (alunite)
R. L. Parker (D)
*McFadden Peak and Blue House Mountain quadrangles, Arizona (asbestos)
A. F. Shride (D)
*Talc and asbestos deposits of north-central Vermont
W. M. Cady (D)
Barite deposits of Arkansas
D. A. Brobst (D)
Bauxite deposits of the Southeastern States
E. F. Overstreet (W)
Eastern Washington clay studies
J. W. Hosterman (W)

Light metals and industrial metals—Continued
*Greenacres quadrangle, Washington and Idaho (high-alumina clays)
P. L. Weis (Spokane, Wash.)
High-alumina weathered basalt on Kauai, Hawaii
S. H. Patterson (W)
Clay deposits of Maryland
M. M. Knechtel (W)
Clay deposits of the Olive Hill bed of eastern Kentucky
J. W. Hosterman (W)
Clay studies, Colorado Plateau
L. G. Schultz (D)
*Lake George district, Colorado (beryllium)
C. C. Hawley (D)
Beryllium in volcanic rocks, Western United States
D. R. Shawe (D)
Fluorspar deposits of northwestern Kentucky
R. D. Trace (Princeton, Ky.)
*Poncha Springs and Bonanza quadrangles, Colorado (fluorspar)
R. E. Van Alstine (W)
*Thomas and Dugway Ranges, Utah (fluorspar-beryllium)
M. H. Staatz (D)
*Beatty area, Nevada (fluorite, bentonite, gold, silver)
H. R. Cornwall (M)
*Western Mojave Desert, California (boron)
T. W. Dibblee, Jr. (M)
*Furnace Creek area, California (boron)
J. F. McAllister (M)
Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
W. C. Smith (M)
*Geology and origin of the saline deposits of Searles Lake, California (boron)
G. I. Smith (M)
Potash and other saline deposits of the Carlsbad area, New Mexico
C. L. Jones (M)
*Heceta-Tuxekan area, Alaska (high-calcium limestone)
G. D. Eberlein (M)
*Chewelah area, Washington (magnesite)
I. Campbell (San Francisco, Calif.)
*Hunters quadrangle, Washington (magnesite, tungsten, base metals, barite)
A. B. Campbell (D)
Mica deposits of the southern Blue Ridge Mountains
F. G. Lesure (W)
Pegmatites of the Spruce Pine and Franklin-Sylva districts, North Carolina
F. G. Lesure (Knoxville, Tenn.)
*Geologic setting of the Spruce Pine pegmatite district, North Carolina (mica, feldspar)
D. A. Brobst (D)
*Southern Black Hills, South Dakota (pegmatite minerals)
J. J. Norton (W)
*Pegmatites of the Custer district, South Dakota
J. A. Redden (Blacksburg, Va.)
*Structure and metamorphism, Hill City quadrangle, South Dakota (pegmatite minerals)
J. C. Rattè (D)
Resources and geochemistry of selenium
D. F. Davidson (D)
Phosphate reserves, Southeastern United States
J. B. Cathcart (D)

Light metals and industrial metals—Continued
Phosphate deposits of northern Florida
G. H. Espenshade (W)
*Florida land-pebble phosphate deposits
J. B. Cathcart (D)
Geochemistry and petrology of westhern phosphate deposits
R. A. Gulbrandsen (M)
*Aspen Range-Dry Ridge area, Idaho (phosphate)
V. E. McKelvey (W)
*Soda Springs quadrangle, Idaho, including studies of the Bannock thrust zone (phosphate)
F. C. Armstrong (Spokane, Wash.)
Stratigraphy and resources of Permian rocks in western Wyoming (phosphate, minor elements)
R. P. Sheldon (D)
Phosphate deposits of south-central Montana
R. W. Swanson (Spokane, Wash.)
Stratigraphy and resources of the Phosphoria Formation in southwestern Montana (phosphate, minor elements)
E. R. Cressman (Lexington, Ky.)
Stratigraphy and resources of the Phosphoria and Park City Formations in Utah and Nevada (phosphate, minor elements)
K. M. Tagg (M)
Geology of monazite
W. C. Overstreet (W)
Geology of the Piedmont region of the Southeastern States (monazite)
W. C. Overstreet (W)
*Shelby quadrangle (monazite)
W. C. Overstreet (W)

Radioactive minerals:
District studies:
Uranium-thorium reconnaissance, Alaska
E. M. MacKevett, Jr. (M)
Mineralogy of uranium-bearing rocks in Karnes and Duval Counties, Texas
A. D. Weeks (W)
Selected studies of uranium deposits, Pennsylvania
H. Klemic (Bowling Green, Ky.)
*Lehighton quadrangle, Pennsylvania (uranium)
H. Klemic (Bowling Green, Ky.)
Uranium and thorium in the White Mountain magma series, New Hampshire
A. P. Butler, Jr. (D)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Relative concentrations of chemical elements in rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (D)
San Rafael Group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (W)

Radioactive minerals—Continued
District studies—Continued
Studies of uranium deposits in Arizona
H. C. Granger (D)
Uranium deposits of the Dripping Spring Quartzite of southeastern Arizona
H. C. Granger (D)
*Carrizo Mountains area, Arizona and New Mexico (uranium)
J. D. Strobell (D)
*Maybell-Lay area, Moffat County, Colorado (uranium)
M. J. Bergin (W)
*Bull Canyon district, Colorado (vanadium, uranium)
C. H. Roach (D)
Exploration for uranium deposits in the Gypsum Valley district, Colorado
C. F. Withington (W)
*Ralston Buttes, Colorado (uranium)
D. M. Sheridan (D)
*Western San Juan Mountains, Colorado (uranium, vanadium, gold)
A. L. Bush (W)
*Slick Rock district, Colorado (uranium, vanadium)
D. R. Shawe (D)
Uravan district, Colorado (vanadium, uranium)
R. L. Boardman (W)
*Ute Mountains, Colorado (uranium, vanadium)
E. B. Ekren (D)
*Powderhorn area, Gunnison County, Colorado (thorium)
J. C. Olson (D)
*Wet Mountains, Colorado (thorium, base, and precious metals)
M R. Brock (D)
Regional relations of the uranium deposits of northwestern New Mexico
L. S. Hilpert (Salt Lake City, Utah)
Ambrosia Lake district, New Mexico (uranium)
H. C. Granger (D)
*Grants area, New Mexico (uranium)
R. E. Thaden (Columbia, Ky.)
Mineralogy of uranium-bearing rocks in the Grants area, New Mexico
A. D. Weeks (W)
*Laguna district, New Mexico (uranium)
R. H. Moench (D)
Alteration in relation to uranium deposits, Laguna district, New Mexico
R. H. Moench (D)
*Tucumcari-Sabinoso area, New Mexico (uranium)
R. L. Griggs (D)
*Abajo Mountains, Utah (uranium, vanadium)
I. J. Witkind (D)
*Circle Cliffs area, Utah (uranium)
E. S. Davidson (Tucson, Ariz.)
*Deer Flat area, White Canyon district, Utah (uranium, copper)
T. L. Finnell (D)
*Elk Ridge area, Utah (uranium)
R. Q. Lewis (Columbia, Ky.)
*La Sal area, Utah and Colorado (uranium, vanadium)
W. D. Carter (Santiago, Chile)
*Lisbon Valley area, Utah and Colorado (uranium, vanadium, copper)
G. W. Weir (Berea, Ky.)

Radioactive minerals—Continued
District studies—Continued
*Moab-Interriver area, east-central Utah (uranium)
E. N. Hinrichs (D)
*Orange Cliffs area, Utah (uranium)
F. A. McKeown (D)
*Sage Plain area, Utah (uranium, vanadium)
L. C. Huff (D)
Uranium ore controls of the San Rafael Swell, Utah
C. C. Hawley (D)
*White Canyon area, Utah (uranium, copper)
R. E. Thaden (Columbia, Ky.)
*Baggs area, Wyoming and Colorado (uranium)
G. E. Prichard (D)
*Crooks Gap area, Fremont County, Wyoming (uranium)
J. G. Stephens (D)
*Gas Hills district, Wyoming (uranium)
H. D. Zeller (D)
*Hiland-Clarkson Hills area, Wyoming (uranium)
E. I. Rich (M)
*Pumpkin Buttes area, Powder River Basin, Wyoming (uranium)
W. N. Sharp (D)
*Southern Powder River Basin, Wyoming (uranium)
W. N. Sharp (D)
*Red Desert area, Wyoming (uranium in coal)
G. N. Pipiringos (D)
*Shirley basin area, Wyoming (uranium)
E. N. Harshman (D)
Strawberry Hill quadrangle, Wyoming (uranium)
R. E. Davis (D)
*Storm Hill quadrangle, Wyoming (uranium)
G. A. Izett (D)
Uranium and phosphate in the Green River Formation, Wyoming
W. R. Keefer (Laramie, Wyo.)
*Southern Black Hills, South Dakota (uranium)
G. B. Gott (D)
*Harding County, South Dakota, and adjacent areas (uraniferous lignite)
G. N. Pipiringos (D)
*Radioactive placer deposits of central Idaho
D. L. Schmidt (D)
*Turtle Lake quadrangle, Washington (uranium)
G. E. Becraft (D)
*Mt. Spokane quadrangle, Washington and Idaho (uranium)
A. E. Weissenborn (Spokane, Wash.)
Commodity and topical studies:
Resource studies and appraisals of radioactive raw materials
A. P. Butler (D)
Uranium-bearing veins
G. W. Walker (D)
Uranium in natural waters
P. W. Fix (W)
Processes of formation and redistribution of uranium deposits
K. G. Bell (D)
Uranium and oil in the Chattanooga Shale
A. Brown (W)
Trace elements in rocks of Pennsylvanian age (uranium, phosphate)
W. Danilchik (Quetta, Pakistan)

Fuels:
District studies:
Petroleum and natural gas:
*Big Stone Gap district, Virginia (oil and gas)
R. L. Miller (W)
*Northern Arkansas oil and gas investigations, Arkansas
E. E. Glick (D)
Central Nebraska basin (oil and gas)
G. E. Prichard (D)
Paleozoic stratigraphy of the Sedgwick Basin, Kansas (oil and gas)
W. L. Adkinson (Lawrence, Kans.)
*Shawnee County, Kansas (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
*Wilson County, Kansas (oil and gas)
H. C. Wagner (M)
McAlester Basin, Oklahoma (oil and gas)
S. E. Frezon (D)
Anadarko Basin, Oklahoma and Texas (oil and gas)
W. L. Adkison (Lawrence, Kans.)
*Wayland quadrangle, Texas (oil and gas)
D. A. Myers (D)
*Franklin Mountains, New Mexico and Texas (petroleum)
R. L. Harbour (D)
Oil and gas fields, New Mexico
D. C. Duncan (W)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota, South Dakota
C. A. Sandberg (D)
*Geology of the Winnett-Mosby area, Montana (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
*Beaver Divide area, Wyoming (oil and gas)
F. B. Van Houten (Princeton, N.J.)
*Crowheart Butte area, Wyoming (oil and gas)
J. F. Murphy (D)
*Shotgun Butte, Wyoming (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Whalen-Wheatland area, Wyoming (oil and gas)
L. W. McGrew (Laramie, Wyo.)
Regional geology of the Wind River Basin, Wyoming (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Fuels potential of the Navajo Reservation, Arizona and Utah
R. B. O'Sullivan (D)
*Eastern Los Angeles basin, California (petroleum)
J. E. Schoellhamer (M)
*Northwest Sacramento Valley, California (petroleum)
R. D. Brown, Jr. (M)
*Gulf of Alaska Tertiary province, Alaska (petroleum)
G. Plafker (M)
**Nelchina area, Alaska (petroleum)
A. Grantz (M)
*Iniskin-Tuxedni region, Alaska (petroleum)
R. L. Detterman (M)
**Lower Yukon-Koyukuk area, Alaska (petroleum)
W. W. Patton, Jr. (M)
**Northern Alaska petroleum investigations
G. Gryc (W)
Coal:
*Warrior quadrangle, Alabama (coal)
W. C. Culbertson (D)
Coal resources of Alabama
W. C. Culbertson (D)

Fuels—Continued
Coal—Continued
*Ivydell, Pioneer, Jellico West, and Ketchen quadrangles, Tennessee (coal)
K. J. Englund (W)
*Eastern Kentucky coal investigations
K. J. Englund (W)
*Allegany County, Maryland (coal)
W. de Witt, Jr. (W)
*Bituminous coal resources of Pennsylvania
E. D. Patterson (W)
Washington County, Pennsylvania (coal)
H. Berryhill, Jr. (D)
*Southern Anthracite field, Pennsylvania
G. H. Wood, Jr. (W)
*Western Middle Anthracite field, Pennsylvania
H. H. Arndt (W)
*Geology and coal resources of Belmont County, Ohio
H. L. Berryhill, Jr. (D)
*Ft. Smith district, Arkansas and Oklahoma (coal and gas)
T. A. Hendricks (D)
*Arkansas Basin coal investigations
B. R. Haley (D)
Coal resources of Iowa
E. R. Landis (D)
*Raton Basin coking coal, New Mexico
G. H. Dixon (D)
*Western Raton coal basin, New Mexico
C. L. Pillmore (D)
*East side San Juan Basin, New Mexico (coal, oil, gas)
C. H. Dane (W)
*Animas River area, Colorado and New Mexico (coal, oil, gas)
H. Barnes (D)
*Carbondale coal field, Colorado
J. R. Donnell (D)
*Eastern North Park, Colorado (coal, oil, gas)
D. M. Kinney (W)
*Western North Park, Colorado (coal, oil, gas)
W. J. Hail (D)
*Trinidad coal field, Colorado
R. B. Johnson (D)
Powder River coal fields, Montana
R. P. Bryson (W)
*Cedar Mountain quadrangle, Iron County, Utah (coal)
P. Averitt (D)
*Southern Kolob Terrace coal field, Utah
W. B. Cashion (D)
Hurricane faults, southwestern Utah (coal)
P. Averitt (D)
*Livingston-Trail Creek area, Montana (coal)
A. E. Roberts (D)
*Maple Valley, Hobart, and Cumberland quadrangles, King County, Washington (coal)
J. D. Vine (M)
*Beluga-Yentna area, Alaska (coal)
F. F. Barnes (M)
*Matanuska coal field, Alaska
F. F. Barnes (M)
Matanuska stratigraphic studies, Alaska (coal)
A. Grantz (M)
*Nenana coal investigations, Alaska
C. Wahrhaftig (M)

Fuels—Continued
Oil shale:
**Oil shale investigations in Colorado
D. C. Duncan (W)
*Grand–Battlement Mesa oil shale, Colorado
J. R. Donnell (D)
*Uinta Basin oil shale, Utah
W. B. Cashion (D)
*Green River Formation, Sweetwater County, Wyoming (oil shale, salines)
W. C. Culbertson (D)
Resource studies:
Fuel-resource studies
D. C. Duncan (W)
Geology of the continental shelves
J. F. Pepper (New Philadelphia, Ohio)
Energy resources of the United States
T. A. Hendricks (D)
Synthesis of geologic data on the Atlantic Coastal Plain and Continental Shelf
J. E. Johnston (W)
Geology and geochemistry of humates
V. E. Swanson (D)
Water:
Distribution and characteristics of streamflow:
Small streams, Alabama
L. E. Carroon (s, Tuscaloosa, Ala.)
Calhoun County surface-water resources, Alabama
J. R. Harkins (s, Tuscaloosa, Ala.)
Sycamore Creek basin, Arizona (water resources)
A. Wilson (s, Tucson, Ariz.)
North Pacific Coast area (surface water)
W. Hofmann (s, M)
Arkansas River basin, Colorado (surface water)
C. T. Jenkins (s, D)
Salinity in the Miami River
S. D. Leach (s, Ocala, Fla.)
Alachua, Bradford, Clay and Union Counties, Florida (surface water)
R. W. Pride (s, Ocala, Fla.)
Enconfina Creek basin area, Florida (water resources)
R. H. Musgrove (s, Ocala, Fla.)
Lake mapping and stabilization, Indiana (surface water)
D. C. Perkins (s, Indianapolis, Ind.)
Water-supply characteristics of Louisiana streams
L. V. Page (s, Baton Rouge, La.)
Bossier-Caddo Parishes, Louisiana (water resources)
L. V. Page (s, Baton Rouge, La.)
Vernon Parish Louisiana (water resources)
L. V. Page (s, Baton Rouge, La.)
Rapides Parish, Louisiana (water resuorces)
L. V. Page (s, Baton Rouge, La.)
North Branch Clinton River basin, Michigan (surface water)
S. W. Wiitala (s, Lansing, Mich.)
Hydrology of a portion of the Humboldt River valley, Nevada
T. W. Robinson (h, M)
Flood and base-flow gaging, New Jersey
E. G. Miller (s, Trenton, N.J.)
Rio Grande basin, New Mexico (surface water)
W. L. Heckler (s, Santa Fe, N. Mex.)
Surface-water resources, Neuse River headwaters, North Carolina
W. E. Forrest (s, Raleigh, N.C.)

Water—Continued
Distribution and characteristics of streamflow—Continued
Beaver Creek basin, Oklahoma (surface water)
L. L. Laine (s, Oklahoma City, Okla.)
Cottonwood Creek basin, Oklahoma (surface water)
L. L. Laine (s, Oklahoma City, Okla.)
Otter Creek basin, Oklahoma (surface water)
A. O. Westfall (s, Oklahoma City, Okla.)
Elk Creek basin, Oklahoma (surface water)
A. O. Westfall (s, Oklahoma City, Okla.)
Puerto Rico (surface water)
D. B. Bogart (s, San Juan, Puerto Rico)
Stream temperature records, Rhode Island
C. E. Knox (s, Boston, Mass.)
Compilation of streamflow records, South Carolina
A. E. Johnson (s, Columbia, S.C.)
Hydrologic investigations, small watersheds, Trinity, Brazos, Colorado, and San Antonio River basins, Texas
W. H. Goines (s, Austin, Tex.)
Chehalis River basin, Washington (surface water)
E. G. Bailey (s, Tacoma, Wash.)
Cedar River basin, Washington (surface water)
F. M. Veatch (s, Tacoma, Wash.)
Floods:
Flood frequency, nationwide
T. Dalrymple (s, W)
Manual on indirect measurements
T. Dalrymple (s, W)
Local floods, Alabama
L. B. Peirce (s, Tuscaloosa, Ala.)
Flood gaging, Alamaba
L. E. Carroon (s, Tuscaloosa, Ala.)
Flood investigations, Maricopa County, Arizona
J. E. Bowie (s, Tucson, Ariz.)
Flood investigations, Arkansas
R. C. Christensen (s, Fort Smith, Ark.)
Floods from small areas in California
L. E. Young (s, M)
Flood gaging, Georgia
C. M. Bunch (s, Atlanta, Ga.)
Flood gaging, Oahu
E. Pearson (s, Honolulu, Hawaii)
Floods from small areas, Illinois
W. D. Mitchell (s, Champaign, Ill.)
Floods from small areas, Iowa
H. H. Schwob (s, Iowa City, Iowa)
Flood investigations, Louisiana
L. V. Page (s, Baton Rouge, La.)
Small-area flood gaging, Minnesota
C. H. Prior (s, St. Paul, Minn.)
Floods from small basins, Mississippi
K. V. Wilson (s, Jackson, Miss.)
Flood investigations on small areas, Missouri
E. H. Sandhaus (s, Rolla, Mo.)
Floods from small areas, Montana
F. C. Boner (s, Helena, Mont.)
Peak discharges from small areas, Nebraska
E. W. Beckman (s, Lincoln, Nebr.)
Flood data in New Jersey
J. E. McCall (s, Trenton, N.J.)
Flood gaging, North Carolina
H. G. Hinson (s, Raleigh, N.C.)

Water—Continued
Floods—Continued
Peak discharges from small areas, North Dakota
O. A. Crosby (s, Bismarck, N. Dak.)
Peak discharges from small areas, South Dakota
R. E. West (s, Pierre, S. Dak.)
Flood gaging, Utah
V. K. Berwick (s, Salt Lake City, Utah)
Flood investigations, Virginia
C. W. Lingham (s, Charlottesville, Va.)
Flood gaging, Wyoming
J. R. Carter (s, Cheyenne, Wyo.)
Low flow and flow duration:
Precipitation records, Alabama
L. E. Carroon (s, Tuscaloosa, Ala.)
Low-flow partial-record investigation, Illinois
D. W. Ellis (s, Champaign, Ill.)
Low-flow gaging, South Carolina
A. E. Johnson (s, Columbia, S.C.)
Low-flow data collection, South Dakota
J. E. Wagar (s, Pierre, S. Dak.)
Low-flow investigations, Texas
W. H. Goines (s, Austin, Tex.)
Water use:
Water management
C. W. Reck (s, W)
Water-supply exploration on the public domain (Western States)
C. T. Snyder (g, M)
Paleontology:
Systematic paleontology:
Ecology of Foraminifera
M. R. Todd (W)
Vertebrate paleontologic studies
F. C. Whitmore, Jr. (W)
Vertebrate paleontologic studies, Western United States
G. E. Lewis (D)
Diatom studies
K. E. Lohman (W)
Stratigraphic paleontology:
Cenozoic geology and paleontology, Atlantic and Gulf Coastal Plains
D. Wilson (W)
Recent Foraminifera, Central America
P. J. Smith (M)
Cenozoic Foraminifera of California
P. J. Smith (M)
Foraminifera of the Lodo Formation, California
M. C. Israelsky (M)
Cenozoic smaller Foraminifera, Pacific Ocean and islands
M. R. Todd (W)
Cenozoic mollusks, Alaska
F. S. MacNeil (M)
Cenozoic mollusks, Oregon
E. J. Moore (M)
Cenozoic mollusks, western Pacific islands
H. S. Ladd (W)
Cenozoic nonmarine mollusks
D. W. Taylor (W)
Cenozoic gastropods and pelecypods, Pacific islands
F. S. MacNeil (M)
Oligocene gastropods and pelecypods, Mississippi
F. S. MacNeil (M)

Paleontology—Continued
Stratigraphic paleontology—Continued
Stratigraphy of the Trent Marl and related units
P. M. Brown (g, Raleigh, N. C.)
Mesozoic stratigraphic paleontology, Pacific coast
D. L. Jones (M)
Mesozoic stratigraphic paleontology of northwestern Montana
W. A. Cobban (D)
Mesozoic gastropods
N. F. Sohl (W)
Cretaceous stratigraphy and paleontology, western interior United States
W. A. Cobban (D)
Upper Cretaceous Foraminifera
M. R. Todd (W)
Cretaceous Foraminifera of the Nelchina area, Alaska
H. R. Bergquist (W)
Post Paleozoic larger Foraminifera
R. C. Douglass (W)
Jurassic stratigraphic paleontology of North America
R. W. Imlay (W)
*Lower Mesozoic stratigraphy and paleontology, Humboldt Range, Nevada
N. J. Silberling (M)
Marine Triassic faunas and stratigraphy
N. J. Silberling (M)
Stratigraphy and paleontology of the Pierre Shale, Front Range area, Colorado and Wyoming
W. A. Cobban and G. R. Scott (D)
Upper Paleozoic brachiopods
J. T. Dutro, Jr. (W)
Permian brachiopods
R. E. Grant (W)
Upper Paleozoic bryozoa and corals
H. Duncan (W)
Upper Paleozoic cephalopods
M. Gordon (M)
Upper Paleozoic conodonts
J. W. Huddle (W)
Upper Paleozoic corals
W. J. Sando (W)
Upper Paleozoic Foraminifera
L. G. Henbest (W)
Upper Paleozoic fusuline Foraminifera
R. C. Douglass (W)
Paleozoic gastropods
E. L. Yochelson (W)
Ostracodes, Upper Paleozioc and younger
I. G. Sohn (W)
Fossil wood and general paleobotany
R. A. Scott (D)
Cenozoic pollen and spores
E. B. Leopold (D)
Tertiary paleobotanical studies
J. A. Wolfe (M)
Paleozoic and Mesozoic pollen and spores
R. H. Tschudy (D)
Paleozoic paleobotany
S. H. Mamay (W)
Upper Paleozoic paleobotany
C. B. Read (Albuquerque, N. Mex.)
Coal lithology and paleobotany
J. M. Schopf (Columbus, Ohio)

Paleontology—Continued
Stratigraphic paleontology—Continued
Subsurface Paleozoic rocks of Florida
J. M. Berdan (W)
Lower Paleozoic corals
W. A. Oliver, Jr. (W)
Lower Paleozoic ostracodes
J. M. Berdan (W)
Upper Silurian and Lower Devonian stratigraphy of Eastern United States
J. M. Berdan (W)
Silurian and Devonian stratigraphic paleontology of the Great Basin and Pacific coast
C. W. Merriam (W)
Ordovician stratigraphic paleontology of the Great Basin and Rocky Mountains
J. Ross, Jr. (D)
Cambrian faunas and stratigraphy
A. R. Palmer (W)

Geomorphology and plant ecology:
Basic research in vegetation and hydrology
R. S. Sigafoos (h, W)
Landform map of Alaska
H. W. Coulter (W)
Vegetation map of Alaska
L. A. Spetzman (W)
Pacific islands vegetation
F. R. Fosberg (W)
Interrelationships between ion distribution and water movement in soils and the associated vegetation
R. F. Miller (h, D)
Plant species or communities as indicators of soil-moisture availability
F. A. Branson (h, D)
Effects of exposure on slope morphology
R. F. Hadley (h, D)
Mass movement and surface runoff in an upland wooded hill slope
L. B. Leopold (w, W)
The hydraulic geometry of a small tidal estuary
L. B. Leopold (w, W)
Stream profiles, Alabama (surface water)
L. B. Peirce (s, Tuscaloosa, Ala.)
Channel-geometry studies, Iowa (surface water)
H. H. Schwob (s, Iowa City, Iowa)
Erosion, sedimentation, and landform development in arid and semi-arid regions
G. G. Parker, R. C. Miller, and I. S. McQueen (h, D)
Piping, an erosional phenomenon in certain silty soils of arid and semi-arid regions
G. G. Parker, R. C. Miller and I. S. McQueen (h, D)
Scour of river beds during high flow
L. B. Leopold (w, W)
Particle movement and channel scour and fill of an ephemeral arroyo near Santa Fe, New Mexico
L. B. Leopold (w, W)
Stream-channel characteristics, North Carolina
W. E. Forrest (s, Raleigh, N.C.)
Solution subsidence of a limestone terrane in southwest Georgia
S. M. Herrick (g, Atlanta, Ga.)
Diagenesis and hydrologic history of the Tertiary limestone of North Carolina
H. E. LeGrand (w, W)

Geomorphology and plant ecology—Continued
Interpretation of hydrogeologic factors
C. W. Carlston (s, W)
Source of base flow of streams
F. A. Kilpatrick (s, Atlanta, Ga.)
River-systems studies, Georgia
A. N. Cameron (s, Atlanta, Ga.)
Relation of geology to low flow, Georgia
O. J. Cosner (s, Atlanta, Ga.)

Glaciology and glacial geology:
Glaciological research
M. F. Meier (h, Tacoma, Wash)
Geomorphology of glacier streams
R. K. Fahnestock (h, Fort Collins, Colo.)
Recognition of late glacial substages in New England and New York
J. E. Upson (g, Mineola, N.Y.)
Hydrology of glacial terrane in the Great Lakes area
R. Schneider (g, W)

Permafrost studies:
Distribution and general characteristics of permafrost
W. E. Davies (W)
Relationship of permafrost to the occurrence of ground water
J. R. Williams (g, Anchorage, Alaska)

Geophysics:
Theoretical and experimental geophysics:
Heat flow and thermal properties
A. H. Lachenbruch (M)
Heat flow in Appalachian Mountains
W. H. Diment (W)
Tension fractures and thermal investigation
A. H. Lachenbruch (M)
Investigation of remanent magnetization of rocks
R. R. Doell (M)
Magnetic properties of rocks
A. Griscom (W)
Analysis of gravity and magnetic anomalies
W. H. Diment (W)
Magnetic model studies
I. Zietz (W)
Polar charts for 3-dimensional magnetic anomalies
R. G. Henderson (W)
Research in geophysical-data interpretation using electronic computers
R. G. Henderson (W)
Propagation of seismic waves in porous media
J. A. daCosta (g, Phoenix, Ariz.)
Electrical properties of rocks
G. V. Keller (D)
Development of electrical methods
C. J. Zablocki (D)
Electrical effects of nuclear explosions
G. V. Keller (D)
Geologic behavior of radon
A. B. Tanner (W)
Development of electromagnetic methods
F. C. Frischknecht (D)
Rock behavior at high temperature and pressure
E. C. Robertson (W)
Heat transfer in salt
E. C. Robertson (W)
Thermodynamic properties
R. A. Robie (W)

Geophysics—Continued
Theoretical and experimental geophysics—Continued
Phase relations in rocks and experimental systems
F. Barker (W)
Evaporite-mineral equilibria
E. Zen (W)
Elastic and anelastic properties of earth materials
L. Peselnick (W)
Ice strength
D. F. Barnes (M)
Geophysical studies of ultramafic intrusions
G. A. Thompson (M)
Infrared and ultraviolet radiation studies
R. M. Moxham (W)
Remote sensing
W. A. Fischer (W)
Nuclear-irradiation studies
C. M. Bunker (D)
Regional geophysical studies:
Gravity map of the United States
H. R. Joesting (W)
Geophysical abstracts
J. W. Clarke (W)
Cross-country aeromagnetic profiles
E. R. King (W)
Correlation of airborne radioactivity data and areal geology
J. A. Pitkin (W)
Aeromagnetic surveys, Eastern United States
R. W. Bromery (W)
Aerial radiological monitoring surveys, Northeastern United States
P. Popenoe (W)
Geophysical studies, New England
M. F. Kane (W)
Geophysical studies of the folded Appalachians
A. Griscom (W)
Aeromagnetic surveys, central United States
J. W. Henderson (W)
Tectonic patterns, Eastern Central United States
I. Zietz (W)
Geophysical studies, Lake Superior region
G. D. Bath (M)
Regional gravity studies in uranium geology, Black Hills area
R. M. Hazelwood (D)
Regional geophysical studies, Colorado Plateau
H. R. Joesting (W)
Geophysical studies, Pacific Southwest
D. R. Mabey (M)
Aeromagnetic surveys, Colorado Plateau and southern Rocky Mountains
H. R. Joesting (W)
Aeromagnetic surveys, Pacific Southwest
D. R. Mabey (M)
Geophysical studies, Pacific Northwest
W. E. Davis (M)
Aeromagnetic surveys, Pacific Northwest
W. E. Davis (M)
Geophysical studies, Arctic
I. Zietz (W)
Geophysical studies, Pacific Ocean
D. F. Barnes (M)

Geophysics—Continued
Regional geophysical studies—Continued
Regional gravity surveys, Alaska
D. F. Barnes (M)
Aeromagnetic surveys, Alaska
D. F. Barnes (M)
Aerial radiological monitoring surveys, Chariot site, Alaska
R. G. Bates (W)
Geophysical studies, Safford Valley, Arizona
G. E. Andreason (W)
Aeromagnetic prospecting for bauxite, Arkansas
A. Jesperson (W)
Aerial radiological monitoring surveys, Los Angeles, California
K. G. Books (W)
Geophysical studies, Sacramento Valley and Coast Range, California
G. D. Bath (M)
Geophysical studies, San Francisco Bay area, California
G. D. Bath (M)
Aerial radiological monitoring surveys, San Francisco, California
J. A. Pitkin (W)
Geophysical studies, Sierra Nevada, California
H. W. Oliver (M)
Aerial radiological monitoring surveys, Rocky Flats, Colorado
J. A. MacKallor (W)
Aerial radiological monitoring surveys, Georgia Nuclear Aircraft Laboratory
J. A. MacKallor (W)
Aerial radiological monitoring surveys, Savannah River Plant, Georgia and South Carolina
R. G. Schmidt (W)
Aerial radiological monitoring surveys, National Reactor Testing Station, Idaho
R. G. Bates (W)
Aerial radiological monitoring surveys, Chicago, Illinois
G. M. Flint, Jr. (W)
Central Iowa aeromagnetic survey
J. R. Henderson (W)
Geophysical studies, Kentucky
J. S. Watkins (W)
Aeromagnetic surveys, Maine
J. W. Allingham (W)
Gravity studies, northern Maine
M. F. Kane (W)
*Geophysical and geologic mapping in the Stratton quadrangle, Maine
A. Griscom (W)
*Electromagnetic and geologic mapping in the Island Falls quadrangle, Maine
F. C. Frischknecht (D)
Geophysical studies, Montgomery County, Maryland
A. Griscom (W)
Geophysical studies, Massachusetts
R. W. Bromery (W)
Aerial radiological monitoring surveys, Elk River, Minnesota
J. A. Pitkin (W)
Aeromagnetic and gravity studies of the Boulder batholith, Montana
W. E. Davis (M)

Geophysics—Continued
Regional geophysical studies—Continued
Gravity and magnetic studies, western Montana
W. T. Kinoshita (M)
Geophysical studies, central Nevada
D. R. Mabey (M)
Gravity investigations, Clark County, Nevada
M. F. Kane (W)
Geophysical studies, Nevada Test Site
R. A. Black (D)
Aeromagnetic surveys, Nevada Test Site
W. J. Dempsey (W)
Aerial radiological monitoring surveys, Nevada Test Site
J. L. Meuschke (W)
Geophysical studies, Upper Rio Grande, New Mexico
G. E. Andreasen (W)
Aerial radiological monitoring surveys, Gnome test site, New Mexico
J. A. MacKallor (W)
Correlation of aeromagnetic studies and areal geology, Adirondacks area, New York
J. R. Balsey (W)
Correlation of aeromagnetic studies and areal geology, New York–New Jersey Highlands
A. Jespersen (W)
Geophysical studies, Concord quadrangle, North Carolina
R. G. Bates (W)
Seismic survey for buried valleys in Ohio
R. M. Hazlewood (D)
Aerial radiological monitoring surveys, Columbus, Ohio
R. G. Bates (W)
Aeromagnetic interpretation, Wichita Mountains system, Oklahoma and Arkansas
A. Griscom (W)
Aeromagnetic and gravity studies, west-central Oregon
R. W. Bromery (W)
Aerial radiological-monitoring surveys, Pittsburgh, Pennsylvania
R. W. Johnson (Knoxville, Tenn.)
Geophysical studies, Puerto Rico
A. Griscom (W)
Aerial radiological-monitoring surveys, Puerto Rico
J. A. Pitkin (W)
Geophysical studies, central eastern Tennessee
R. W. Johnson (Knoxville, Tenn.)
Aerial radiological monitoring surveys Oak Ridge National Laboratory, Tennessee
R. G. Bates (W)
*Geophysical and geological studies, Texas coastal plain
D. H. Eargle (Austin, Tex.)
Aerial radiological monitoring surveys, Forth Worth, Tex.
J. A. Pitkin (W)
Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
S. K. Neuschel (W)
Geophysical studies, northeastern Washington
W. T. Kinoshita (M)
Aerial radiological monitoring surveys, Hanford, Washington
R. G. Schmidt (W)
Gravity survey, western Washington
D. J. Stuart (D)

Geophysics—Continued
Regional geophysical studies—Continued
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J. W. Allingham (W)
Major crustal studies:
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L. C. Pakiser (D)
Gravity studies of major crustal units
D. J. Stuart (D)
Long seismic profiling
W. H. Jackson (D)
Seismic network, Rocky Mountain area
J. P. Eaton (D)
Traveltime data analysis of seismic waves
J. C. Healy (D)
Geochemistry and mineralogy:
Experimental geochemistry—hydrothermal silicate systems
D. B. Stewart, D. R. Wones, and H. R. Shaw (W), and J. Hemley and P. Hostetler (D)
Compositions of supercritical fluids in the system K_2O-Al_2O_3-SiO_2-H_2O
C. J. Spengler (q, Arlington, Va.)
Experimental geochemistry—metallic sulfides and sulfosalt systems
B. J. Skinner, E. H. Roseboom, Jr., P. B. Barton, Jr., P. M. Bethke, and P. Toulmin, III (W)
Experimental geochemistry—alkali and alkaline earth salt systems
E-an Zen (W)
Thermodynamic properties of minerals
R. A. Robie, B. J. Skinner, P. B. Barton, Jr., P. M. Bethke, and P. Toulmin, III (W)
Geologic thermometry
B. J. Skinner (W)
Solubilities of minerals in aqueous fluids
C. A. Kinzer and P. B. Barton, Jr. (W) and J. Hemley and P. Hostetter (D)
Solution-mineral equilibria
C. L. Christ (W)
Hydrothermal solubility
G. W. Morey (W)
Chemical composition of thermal waters in Yellowstone Park
G. W. Morey (W)
Environment of ore deposition
P. M. Bethke (W)
Fluid inclusions in minerals
E. W. Roedder (W)
Experimental studies on rock weathering and alteration
J. J. Hemley (D)
Sedimentary mineralogy
J. C. Hathaway (D)
Crystal chemistry
H. T. Evans, Jr. (W)
Mineralogical studies and description of new minerals
D. E. Appleman (W)
Crystal chemistry of borate minerals
J. R. Clark and C. L. Christ (W)
Experimental mineralogy and crystal chemistry—phosphate minerals
D. E. Appleman (W)

Geochemistry and mineralogy—Continued
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M. E. Mrose (W)
Experimental mineralogy and crystal chemistry—rock-forming silicate minerals
D. E. Appleman (W)
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H. T. Evans (W)
Petrological services and research
C. Milton (W)
Mineralogy and geochemistry of the Green River Formation, Wyoming
C. Milton (W)
Mineralogic services and research
A. D. Weeks (W)
Mineralogic services and research
T. Botinelly (D)
Mineralogical studies and description of new minerals—micas and chlorites
M. D. Foster (W)

Field geochemistry and petrology:
Geological, geochemical, and geophysical studies of Hawaiian volcanology
D. H. Richter (Hawaii)
Studies of welded tuff
R. L. Smith (W)
*Petrology of the Valles Mountains, New Mexico
R. L. Smith (W)
*Petrology of the Bearpaw Mountains, Montana
W. T. Pecora (W)
Petrology and chromite resources of the Stillwater ultramafic complex, Montana
E. D. Jackson (M)
*Petrology of the Wolf Creek area, Montana
R. G. Schmidt (W)
Petrology of volcanic rocks, Snake River Valley, Idaho
H. A. Powers (D)
*Petrology and volcanism, Katmai National Monument, Alaska
G. H. Curtis (M)
*Petrology of the Burney area, California
G. A. Macdonald (Honolulu, Hawaii)
Petrology and geochemistry of the Laramide intrusives in the Colorado Front Range
G. Phair (W)
Wallrock alteration and its relation to thorium deposition in the Wet Mountains, Colorado
G. Phair (W)
Petrology and geochemistry of the Boulder Creek batholith, Colorado Front Range
G. Phair (W)
Origin and characteristics of thermal and mineral waters
D E. White (M)
Investigation of hydrothermal jasperoid
T. G. Lovering (D)
Metamorphism and origin of mineral deposits, Gouverneur area, New York
A. E. J. Engel (Pasadena, Calif.)
Glaucophane schist terranes within the Franciscan Formation, California
R. G. Coleman (M)

Field geochemistry and petrology—Continued
*Geochemistry and metamorphism of the Belt Series; Clark Fork and Packsaddle Mountain quadrangles, Idaho and Montana
J. E. Harrison (D)
*Metamorphism of the Orofino area, Idaho
A. Hietanen-Makela (M)
Chemical and physical properties of the Pierre Shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
Geology and paleolimnology of the Green River Formation, Wyoming
W. H. Bradley (W)
Stratigraphy and mineralogy of cave deposits
W. E. Davies (W)
Sedimentary-petrology laboratory
H. A. Tourtelot (D)
Model studies of structures in sediments
E. D. McKee (D)

Geochemical distribution of the elements:
Geochemical distribution of elements
M. Fleischer (W)
Geochemical compilation of rock analyses
M. Hooker (W)
Chemical composition of sedimentary rocks
H. A. Tourtelot (D)
Geochemistry of minor elements
G. Phair (W)
Minor elements in volcanic rocks
R. R. Coats (M)
Minor elements in coal
P. Zubovic (W)
Occurrence and distribution of minor elements in fresh and saline waters of California
W. D. Silvey (q, Sacramento, Calif.)
Coding and retrieval of geologic data
D. F. Davidson (D)
Synthesis of ore-mineral data
W. E. Hall (W)
Geochemical sampling and statistical analysis of data
A. T. Miesch (D)
Distribution of elements in Mount Princeton area, Colorado
P. Toulmin (W)
Distribution of beryllium, Mt. Wheeler mine area, Nevada
D. E. Lee (M)
Geochemical survey of the Driftless Area, Wisconsin
H. T. Shacklette (D)

Geochemistry of water:
Mineral constituents in ground water and their origin
J. H. Feth (g, M)
Hydrosolic metals in natural water
J. D. Hem (q, D)
Spatial distribution of chemical constituents in ground water, Eastern United States
W. Back (g, W)
Organic substances in water
W. L. Lamar (q, M)
Occurrence and distribution of the rare halogens
I. Barnes (q, Arlington, Va.)

Geochemistry of water—Continued
- Occurrence and distribution of strontium in natural water
  - M. W. Skougstad (q, D)
- Geochemistry of ground water in the Englishtown Formation
  - P. R. Seaber (g, Trenton, N.J.)
- Fluoride in ground waters of Horry County area, South Carolina
  - N. Baker (q, Arlington, Va.)
- Quality of water as controlled by weathering of clay minerals
  - I. Barnes (q, Arlington, Va.)
- Compacted clay minerals as semipermeable membranes and their effect on water chemistry
  - B. B. Hanshaw (g, W)
- Mineralogy and exchange capacity of fluvial sediments
  - V. C. Kennedy (q, D)
- The petrology and chemistry of the San Andres Limestone and their relation to the quality of water in the Acoma-Laguna area, Valencia County, New Mexico
  - H. E. Koester (q, Albuquerque, N. Mex.)
- Fluvial denudation in the United States. Phase 2.—Variance in water quality and environment
  - F. H. Rainwater (q, W)
- Solute composition and minor-element distribution in lacustrine closed basins
  - B. F. Jones (q, W)
- Solute-solid relations in lacustrine closed basins of the alkali-carbonate type
  - B. F. Jones (q, W)

Isotope and nuclear studies:
- Stable isotopes of light elements in rocks, minerals and waters
  - I. Friedman (W)
- Isotope ratios in rocks and minerals
  - I. Friedman (W)
- Radioactive nuclides in minerals
  - F. E. Senftle (W)
- Isotope geology of lead
  - R. S. Cannon, Jr. (D)
- Isotopes in studies of crustal processes
  - B. Doe (W)
- Investigations in isotopic hydrology
  - L. L. Thatcher (q, W)
- Tritium in ground water in the Roswell Basin, New Mexico
  - J. W. Hood (g, Albuquerque, N. Mex.)
- Tritium as a tracer in the Ogallala Formation in the High Plains, Lea County, New Mexico
  - H. O. Reeder (g, Albuquerque, N. Mex.)
- Tritium as a tracer in the Lake McMillan underground reservoir, New Mexico
  - H. O. Reeder (g, Albuquerque, N. Mex.)
- Occurrence and distribution of radioelements in water
  - R. C. Scott (q, D)
- Removal of radionuclides from water by earth materials of the Nevada Test Site
  - W. A. Beetem (q, D)
- Magnetic susceptibility of minerals
  - F. E. Senftle (W)
- Measurement of magnetic properties of rocks
  - A. N. Thorpe (W)

Isotope and nuclear studies—Continued
- Nuclear irradiation
  - C. M. Bunker (D)
- Electronics laboratory
  - W. W. Vaughn (D)
- Instrument development
  - F. J. Jurceka (D)
- Density comparison method for determining oxygen isotope ratios
  - J. H. McCarthy, Jr. (D)
- Oxygen-isotope geothermometry
  - H. L. James (Minneapolis, Minn.)

Geochronology:
- Geologic-time scale
  - S. S. Goldich (W)
- Geochronology: carbon-14 method
  - M. Rubin (W)
- Geochronology: lead-alpha ages of rocks
  - T. W. Stern (W)
- Geochronology: lead-uranium ages of mineral deposits
  - L. R. Stieff (W)
- Geochronology: K/A and Rb/Sr methods
  - H. H. Thomas and C. Hedge (W), and R. Kistler (M)
- Radiogenic daughter products
  - J. N. Rosholt (D)

Hydraulic and hydrologic studies:

General hydrology:
- Hydrology of the public domain (small basins)
  - H. V. Peterson (h, M)
- Textbook on ground-water geology
  - A. N. Sayre (w, W)
- Problems in quantitative hydrology
  - M. I. Rorabaugh (g, Tallahassee, Fla.)
- Analog-model—unsteady-state flow
  - H. E. Skibitzke (g, Phoenix, Ariz.)
- Statistical inferences
  - N. C. Matalas (s, W)
- Effects of heterogeneity
  - H. E. Skibitzke (g, Phoenix, Arix.)
- Correlation of monthly streamflow
  - R. O. R. Martin (s, W)
- Automatic data processing
  - W. L. Isherwood (s, W)
- Modification of digital recorders
  - W. L. Isherwood (s, W)

Open-channel hydraulics and fluvial sediments:
- Theory of multiphase flow—applications
  - R. W. Stallman (g, D)
- Sediment transport and channel roughness in natural and artificial channels
  - T. Maddock, Jr. (h, W)
- Turbulence diffusion
  - N. Yotsukura (s, W)
- Influence of smooth boundaries on shear
  - H. J. Tracy (s, Atlanta, Ga.)
- Distribution of shear
  - J. Davidian (s, W)
- Unsteady flow in natural channels
  - C. Lai (s, W)
- Variation in velocity-head coefficient
  - H. Hulsing (s, M)
- Verification of hydraulic techniques
  - J. S. Cragwall, Jr. (s, Chattanooga, Tenn.)

Hydraulic and hydrologic studies—Continued
Open-channel hydraulics and fluvial sediments—Continued
Effects of sediment characteristics on fluvial morphology hydraulics
S. A. Schumm (h, D)
Changes below dams (river channels)
M. G. Wolman (h, Baltimore, Md.)
Evaluation of sediment barrier on Sheep Creek, Paria River Basin, near Tropic, Utah
G. C. Lusby (h, D)
Roughness in alluvial channels and sediment transportation
D. B. Simons (q, Fort Collins, Colo.)
Factors affecting sediment transport—graphical representation of factors affecting bed-material discharge of sand-bed streams
B. R. Colby (q, Lincoln, Nebr.)
Sediment-transport parameters in sand-bed streams
C. F. Nordin, Jr. (q, Albuquerque, N. Mex.)
Flow phenomena and sediment transport in streams with high concentrations of fine material
C. F. Nordin (q, Albuquerque, N. Mex.)
Techniques for utilization of sediment reconnaissance data
H. P. Guy (q, W)
Sediment manual
R. B. Vice (q. A)
Study of precipitation runoff and sediment yield in Cornfield Wash, New Mexico
D. E. Burkham (h, Albuquerque, N. Mex.)
Study of channel flood-plain aggradation, Tusayan Washes, Arizona
R. F. Hadley (h, D)
General studies of erosion and sedimentation
G. G. Parker (h, D)
Mechanics of hillslope erosion
S. A. Schumm (h, D)
Hydrologic effect of vegetation modification, Arizona
R. C. Culler (s, Tucson, Ariz.)
Effect of removing riparian vegetation, Cottonwood Wash, Arizona (water)
J. E. Bowie (s, Tucson, Ariz.)
Surface-water hydrology:
Synthetic hydrology
M. A. Benson (s, W)
River-systems gaging
H. C. Riggs (s, W)
Analog models of flood flows
J. Shen (s, Tucson, Ariz.)
Long-term chronologies of hydrologic events (nationwide)
W. D. Simons (s, Tacoma, Wash.)
Natural diurnal fluctuations in streams
R. E. Oltman (s, W)
Ice in streams
R. W. Carter (s, W)
Hydrologic effect of urbanization
A. O. Waananen (h, M)
Hydrologic effect of vegetation modification
R. C. Culler (h, Tucson, Ariz.)
Snowmelt hydrology of a Sierra Nevada stream
W. Hofmann (s, M)
Special studies, surface water, Florida
R. W. Pride (s, Ocala, Fla.)

Hydraulic and hydrologic studies—Continued
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Hydrologic studies, Hawaii
G. T. Hirashima (s, Honolulu, Hawaii)
Hydrology of small streams, New Hampshire
C. E. Knox (s, Boston, Mass.)
Analyses of streamflow characteristics, South Carolina
A. E. Johnson (s, Columbia, S.C.)
Special hydrologic studies, Texas
W. B. Mills (s, Austin, Tex.)
Special flood and hydrologic investigations, Texas
W. H. Goines (s, Austin, Tex.)
Hydrologic and hydraulic studies, Virginia
C. W. Lingham (s, Charlottesville, Va.)
Hydrology of lower Flett Creek basin, Washington
F. M. Veatch (s, Tacoma, Wash.)
General hydrology, West Virginia
W. L. Doll (s, Charleston, W. Va.)
Ground-water flow studies:
Mechanics of fluid flow in porous media
A. Ogata (g, Honolulu, Hawaii)
Mechanics of aquifers—principles of compaction and deformation
J. F. Poland (g, Sacramento, Calif.)
Mechanics of diffusion, fresh and salt water
H. H. Cooper (g, Tallahassee, Fla.)
Treatise on ground-water mechanics
J. G. Ferris (g, W)
Theory of unsaturated flow
H. E. Skibitzke (g, Phoenix, Ariz.)
Unsaturated flow in porous media
W. O. Smith (g, W)
Unsaturated flow, National Reactor Testing Station
P. H. Jones (g, Boise, Idaho)
Transient flow in saturated porous media
W. O. Smith (g, W)
Specific-yield research
A. I. Johnson (g, D)
Liquid movement in clays
H. W. Olsen (g, W)
Mechanics of artesian systems and aquifers
S. W. Lohman (g, D)
Agricultural Research Service soil-moisture study
R. E. Evenson (g, Sacramento, Calif.)
Directional permeability of marine sandstones
R. R. Bennett (g, W)
Mathematical relationships of directional permeability and of nonhomogeneity
J. A. daCosta (g, Phoenix, Ariz.)
Columbia River Basalt hydrology
R. C. Newcomb (g, Portland, Oreg.)
Limestone-terrane hydrology
F. A. Swenson (g, D)
Glacial-terrane hydrology
R. Schneider (g, W)
Geohydrologic environment as related to water utilization in arid lands
E. S. Davidson (g, Tucson, Ariz.)
Geohydrologic environmental study
J. N. Payne (g, Baton Rouge, La.)
Hydrologic and physical properties of soils and rocks
D. A. Morris (g, D)

Hydraulic and hydrologic studies—Continued
Ground-water flow studies—Continued
Lower Colorado River Basin hydrology
C. C. McDonald (g, Yuma, Ariz.)
Artificial recharge, Grand Prairie region, Arkansas (ground water)
R. T. Sniegocki (g, Little Rock, Ark.)
Artificial recharge of aquifers
R. T. Sniegocki (g, Little Rock, Ark.)
Feasibility of artificial recharge of the Snake Plain aquifer, Idaho
M. J. Mundorff (g, Boise, Idaho)
Artificial recharge at Kalamazoo, Michigan
J. E. Reed (g, Lansing, Mich.)
Recharge studies on the High Plains, New Mexico
J. S. Havens (g, Albuquerque, N. Mex.)
Artificial recharge of basalt aquifers at The Dalles, Oregon
B. L. Foxworthy (g, Portland, Oreg.)
Artificial recharge of basalt aquifers at Salem Heights, Oregon
B. L. Foxworthy (g, Portland, Oreg.)
Artificial recharge of basalt aquifers, Walla Walla, Washington
A. A. Garrett (g, Tacoma, Wash.)

Limnological problems:
Temperature of lake waters, Alabama
L. E. Carroon (s, Tuscaloosa, Ala.)
Physical characteristics of selected Florida lakes
W. E. Kenner (s, Ocala, Fla.)
Hydrology and hydrochemistry of Lake Abert, Oregon
K. N. Phillips (s, Portland, Oreg.)
Hydrology of prairie pot holes
Wm. S. Eisenlohr (h, D)

Evapotranspiration:
Mechanics of evaporation
J. S. Meyers (s, D)
Evaporation measurement
J. S. Meyers (s, D)
Evapotranspiration theory and measurement
O. E. Leppanen (h, Phoenix, Ariz.)
Evapotranspiration study
O. E. Leppanen (h, Phoenix, Ariz.)
Natural water loss, southern California
W. Hofmann (s, M)
Reservoir evaporation, San Diego County, California
W. Hofmann (s, M)
Use of water by saltcedar in evapotranspirometer compared with energy-budget and mass-transfer computation
T. E. A. Van Hylckama (h, Phoenix, Ariz.)
Study of water application and use on a range water spreader in northeast Montana
F. A. Branson (h, D)

Geology applied to construction and terrain problems:
Engineering soils map of Alaska
T. N. V. Karlstrom (W)
Rock-types map of Alaska
L. A. Yehle (W)
*Surficial- and engineering-geology studies and construction-materials sources, Alaska
T. L. Péwé (College, Alaska)

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*Surficial geology of the Anchorage-Matanuska Glacier area, Alaska (construction-site planning)
T. N. V. Karlstrom (W)
Surficial geology of the Bristol Bay area, Alaska (construction-site planning)
H. R. Schmoll (W)
*Surficial geology of the lower Chitina Valley, Alaska (construction-site planning)
L. A. Yehle (W)
*Surficial geology of the northeastern Copper River basin, Alaska (construction-site planning)
O. J. Ferrians, Jr. (Glennallen, Alaska)
*Surficial geology of the southeastern Copper River basin, Alaska (construction-site planning)
D. R. Nichols (W)
*Surficial geology of the southwestern Copper River basin, Alaska (construction-site planning)
J. R. Williams (W)
*Surficial geology of the eastern Denali Highway, Alaska (construction-site planning)
D. R. Nichols (W)
*Surficial geology of the Johnson River district, Alaska (construction-site planning)
H. L. Foster (W)
*Surficial geology of the Kenai lowland, Alaska (construction-site planning)
T. N. V. Karlstrom (W)
**Kobuk River valley, Alaska (construction-site planning)
A. T. Fernald (W)
*Mt. Hayes D-3 and D-4 quadrangles, Alaska (construction-site planning)
T. L. Péwé (College, Alaska)
*Surficial geology of the Seward-Portage Railroad belt, Alaska (construction-site planning)
T. N. V. Karlstrom (W)
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W. E. Davies (W)
*Surficial geology of the Upper Tanana River, Alaska (construction-site planning)
A. T. Fernald (W)
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F. R. Weber (College, Alaska)
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*Black Canyon of the Gunnison River, Colorado (construction-site planning)
W. R. Hansen (D)
Engineering geology of the Roberts Tunnel, Colorado
C. S. Robinson (D)
*Fort Peck area, Montana (construction-site planning)
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*Wolf Point area, Montana (construction-site planning)
R. B. Colton (D)
*Upper Green River Valley, Utah (construction-site planning)
W. R. Hansen (D)
*Surficial geology of the Oak City area, Utah (construction-site planning)
D. J. Varnes (D)
*Herndon quadrangle, Virginia (construction-site planning)
R. E. Eggleton (D)
Urban areas:
*Surficial geology of the Beverly Hills, Venice, and Topanga quadrangles, Los Angeles, California (urban geology)
J. T. McGill (Los Angeles, Calif.)
*Malibu Beach quadrangle, California (urban geology)
R. F. Yerkes (M)
*Oakland East quadrangle, California (urban geology)
D. H. Radbruch (M)
*Point Dume quadrangle, California (urban geology)
J. E. Schoellhamer (M)
*San Francisco Bay area, San Francisco South quadrangle, California (urban geology)
M. G. Bonilla (M)
*San Francisco Bay area; San Francisco North quadrangle, California (urban geology)
J. Schlocker (M)
*San Mateo quadrangle, California (urban geology)
G. O. Gates (M)
*Denver metropolitan area, Colorado (urban geology)
R. M. Lindvall (D)
*Golden quadrangle, Colorado (urban geology)
R. Van Horn (D)
*Morrison quadrangle, Colorado (urban geology)
J. H. Smith (D)
*Pueblo and vicinity, Colorado (urban geology)
G. R. Scott (D)
*Beltsville quadrangle, Maryland (urban geology)
C. F. Withington (W)
Research and application of geology and seismology to public-works planning, Massachusetts
C. R. Tuttle and R. N. Oldale (Boston, Mass.)
*Greats Falls area, Montana (urban geology)
R .W. Lemke (D)
*Omaha–Council Bluffs and vicinity, Nebraska and Iowa (urban geology)
R. D. Miller (D)
*Portland industrial area, Oregon and Washington (urban geology)
D. E. Trimble (D)
*Knoxville and vicinity, Tennessee (urban geology)
J. M. Cattermole (Columbia, Ky.)
*Puget Sound Basin, Washington (urban geology)
D. R. Crandell (D)
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D. R. Mullineaux (D)
Engineering geology, Washington, D.C., metropolitan area
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Engineering problems related to rock failure:
Geologic factors involved in subsidence
A. S. Allen (W)

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Deformation research
S. P. Kanizay (D)
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T. C. Nichols, Jr. (D)
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Sea-cliff erosion studies
C. A. Kaye (Boston, Mass.)
Mining hydrology
W. T. Stuart (g, W)
*Geologic factors related to coal-mine bumps, Utah
F. W. Osterwald (D)
Landslide studies in the Fort Randall Reservoir area, South Dakota
H. D. Varnes (D)
Nuclear test-site studies:
Nuclear-explosion effects
W. E. Hale (D)
Site-selection studies
J. D. Friedman (W)
Test-site evaluation, seismic-improvement studies
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W. S. Twenhofel (D)
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*Engineering geology of Gnome Test Site, New Mexico
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*Nash Draw quadrangle, New Mexico (test-site evaluation)
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W. S. Twenhofel (D)
*Engineering geology of the Nevada Test Site area
V. R. Wilmarth (D)
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V. R. Wilmarth (D)
Yucca Valley and Frenchman Valley engineering geology, Nevada Test Site
F. N. Houser (D)
Site-evaluation, underground air storage, Nevada Test Site
R. B. Johnson (D)
Analysis of hydrologic data:
Photointerpretation to aid hydrologic studies
W. J. Schneider (s, W)
Electronic-equipment development
J. E. Eddy (g, W)
Analog-model unsaturated flow
H. E. Skibitzke (g, Phoenix, Ariz.)
Land-use evaluation
F. W. Kennon (h, Oklahoma City, Okla.)
Effect of mechanical treatment on arid land in the Western United States
F. A. Branson (h, D)
Hydrologic effect of small reservoirs, Honey Creek, Texas
F. W. Kennon (h, Oklahoma City, Okla.)

Analysis of hydrologic data—Continued

Effects of grazing exclusion in Badger Wash area, Colorado
G. C. Lusby (h, D)

Use of flood-volume data
G. A. Kirkpatrick (s, W)

Unit graphs and infiltration rates, Alabama (surface water)
L. B. Peirce (s, Tuscaloosa, Ala.)

Bridge-site studies, Alabama (water resources)
L. B. Peirce (s, Tuscaloosa, Ala.)

Flood inundation, Lower Eel River, California
W. Hofmann (s, M)

Bridge-site studies, Florida (surface water)
R. W. Pride (s, Ocala, Fla.)

Areal flood studies, Georgia
C. M. Bunch (s, Atlanta, Ga.)

Bridge-site investigations, Georgia (surface water)
C. M. Bunch (s, Atlanta, Ga.)

Flood investigations, Idaho
S. O. Decker (s, Boise, Ida.)

Bridge-site studies, Illinois (surface water)
W. D. Mitchell (s, Champaign, Ill.)

Northeastern Illinois inundation mapping
W. D. Mitchell (s, Champaign, Ill.)

Flood profiles and flood-frequency studies, Iowa
H. H. Schwob (s, Iowa City, Iowa)

Flood investigations, Kansas
L. W. Furness (s, Topeka, Kans.)

Flood-frequency study, Kentucky
J. A. McCabe (s, Louisville, Ky.)

Bridge-site studies, Kentucky (surface water)
C. H. Hannum (s, Louisville, Ky.)

Drainage-area compilation, Kentucky
H. C. Beaber (s, Louisville, Ky.)

Rainfall-runoff relations, Kentucky
J. A. McCabe (s, Louisville, Ky.)

Flood-frequency analysis, Minnesota
C. H. Prior (s, St. Paul, Minn.)

Drainage-area determination, Mississippi
J. D. Shell (s, Jackson, Miss.)

Bridge-site studies, Mississippi (surface water)
K. V. Wilson (s, Jackson, Miss.)

Bridge-site studies, Nebraska (surface water)
E. W. Beckman (s, Lincoln, Nebr.)

Flood investigations, Nevada
E. E. Harris (s, Carson City, Nevada)

Flood-plain inundation studies, New Jersey
R. H. Tice (s, Trenton, N.J.)

Flood warning, New Jersey
J. E. McCall (s, Trenton, N.J.)

Flow probability of New Jersey streams
E. G. Miller (s, Trenton, N.J.)

Flood-frequency relations, New Mexico
L. A. Wiard (s, Santa Fe, N. Mex.)

Flood-frequency studies, North Carolina
W. E. Forrest (s, Raleigh, N.C.)

Flood-inundation mapping, Puerto Rico
D. B. Bogard (s, San Juan, Puerto Rico)

Drainage-area determinations, South Carolina
W. M. Bloxham (s, Columbia, S.C.)

Flood-frequency studies, South Carolina
F. H. Wagener (s, Columbia, S.C.)

Analysis of hydrologic data—Continued

Santee River basin flood study, South Carolina
A. E. Johnson (s, Columbia, S.C.)

Flood-frequency analysis, Tennessee
W. J. Randolph (s, Chattanooga, Tenn.)

Bridge-site studies, Tennessee (surface water)
I. J. Hickenlooper (s, Chattanooga, Tenn.)

Flood profiles, Chattanooga Creek, Tennessee
A. M. F. Johnson (s, Chattanooga, Tenn.)

Drainage-area determinations, Texas
P. H. Holland (s, Austin, Tex.)

Flood-frequency studies, Texas
W. H. Goines (s, Austin, Tex.)

Flood hydrology, Fairfax County and Alexandria City, Virginia
D. G. Anderson (s, Charlottesville, Va.)

Regional flood frequency, Wisconsin
D. W. Ericson (s, Madison, Wisc.)

Bridge-site studies, Wyoming
J. R. Carter (s, Cheyenne, Wyo.)

Bank-seepage studies
E. C. Pogge (s, Iowa City, Iowa)

Water-loss and water-gain studies in California
W. C. Peterson (s, M)

Marquette Iron Range, Michigan (water resources)
S. W. Wiitala (s, Lansing, Mich.)

Low-flow frequency studies, Arkansas
J. L. Patterson (s, Fort Smith, Ark.)

Low-flow studies, Georgia
R. F. Carter (s, Atlanta, Ga.)

Low-flow frequency analyses
W. D. Mitchell (s, Champaign, Ill.)

Low-flow characteristics, Indiana
R. E. Hoggatt (s, Indianapolis, Ind.)

Low-flow frequency studies, Iowa
H. H. Schwob (s, Iowa City, Iowa)

Low-flow frequency and flow duration, Kentucky
J. A. McCabe (s, Louisville, Ky.)

Low-flow analyses, Maryland
L. W. Lenfest (s, College Park, Md.)

Low-flow characteristics, Massachusetts
G. K. Wood (s, Boston, Mass.)

Low-flow characteristics, Mississippi
H. G. Golden (s, Jackson, Miss.)

Low-flow characteristics of Missouri streams
H. C. Bolon (s, Rolla, Mo.)

Streamflow records analyzed by electronic computer
E. G. Miller (s, Trenton, N.J.)

Interpretation of data, North Carolina (surface water)
G. C. Goddard (s, Raleigh, N.C.)

Low-flow and storage requirements, Ohio
W. P. Cross (s, Columbus, Ohio)

Low-flow frequency, Red River of the North, North Dakota
H. M. Erskine (s, Bismarck, N. Dak.)

Low-flow frequency analysis, Pennsylvania
W. F. Busch (s, Harrisburg, Pa.)

Low-flow studies, Tennessee
J. S. Cragwall, Jr. (s, Chattanooga, Tenn.)

Low-flow frequency analyses, Wisconsin
K. B. Young (s, Madison, Wis.)

Evaporation suppression
G. E. Koberg (s, D)

Analysis of hydrologic data—Continued
Stream sanitation and water supply, North Carolina
G. C. Goddard (s, Raleigh, N.C.)
Thermal pollution of streams
G. E. Harbeck (h, D)
Model studies (water)
E. V. Richardson (s, Fort Collins, Colo.)
Data measurement and instrumentation (water)
C. R. Daum (s, D)
Instrumentation research (water)
E. G. Barron (s, Columbus, Ohio)
Ultrasonic measuring equipment
W. Hofmann (s, M)
Automation and processing techniques for water-quality data
G. A. Billingsley (q, Raleigh, N.C.)
A study of methods used in measurement and analysis of sediment loads in streams
B. C. Colby (q, Minneapolis, Minn.)
Discharge characteristics of weirs and dams
C. E. Kindsvater (s, Atlanta, Ga.)

Radioactive waste disposal investigations:
Geochemical problems of radioactive-waste disposal
H. H. Waesche (W)
Geology of the Anadarko Basin, Oklahoma, with reference to disposal of high-level radioactive wastes
M. MacLachlan (D)
Geology of the Appalachian Basin with reference to disposal of high-level radioactive wastes
G. W. Colton (W)
Geology of the Powder River basin, Wyoming, with reference to the disposal of high-level radioactive wastes
H. Beikman (D)
Geology of the Williston Basin with reference to the disposal of high-level radioactive wastes
C. A. Sandberg (D)
Distribution and concentration of radioactive waste in streams by fluvial sediments
D. W. Hubbell (q, Fort Collins, Colo.)
Exchange phenomena and chemical reactions of radioactive substances
J. H. Baker (q, D)
Geology and ground-water hydrology of the Atlantic and Gulf Coastal Plains as related to disposal of radioactive wastes
H. E. LeGrand (w, W)
Geology and hydrology of the Central and Northeastern States as related to the management of radioactive materials
W. C. Rasmussen (g, Newark, Del.)
Geology and hydrology of the Great Plains States as related to the management of radioactive materials
W. C. Rasmussen (g, Newark, Del.)
Geology and hydrology of the Western States as related to the management of radioactive materials
R. W. Maclay (g, St. Paul, Minn.)
Geology, hydrology, and waste disposal at the National Reactor Testing Station, Idaho
R. L. Nace (w, W)
Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho
P. H. Jones (g, Boise, Idaho)

Radioactive waste disposal investigations—Continued
Research on hydrology, National Reactor Testing Station, Idaho
E. H. Walker (g, Boise, Idaho)
Ground-water studies in conjunction with Project Gnome, Eddy County, New Mexico
J. B. Cooper (g, Albuquerque, N. Mex.)
Movement of water and radioactive materials in the Bandelier Tuff, Los Alamos, New Mexico
J. H. Abrahams (g, Albuquerque, N. Mex.)
Waste-contamination studies at Los Alamos (ground water)
J. H. Abrahams (g, Albuquerque, N. Mex.)
Rocky Mountain Arsenal, Colorado (ground water)
M. C. Van Lewen (g, D)
Nevada Test Site (ground water)
S. L. Schoff (g, D)

Distribution of elements as related to health:
Distribution of radioactivity
S. Rosenblum (W)
Botanical exploration and research
H. L. Cannon (D)
Botanical research, San Juan County, New Mexico
H. L. Cannon (D)
Colorado Plateau botanical-prospecting studies
F. J. Kleinhampl (M)
Cadmium-chromium contamination in ground water in Nassau County, New York
N. J. Lusczynski (g, Albany, N.Y.)
Behavior of detergents and other pollutants in soil-water environments
C. H. Wayman (q, D)
Effects of organisms on water quality of streams
K. V. Slack (q, Arlington, Va.)
Water-quality conservation in the Arkansas and Red River basins, Oklahoma
P. E. Ward (g, Norman, Okla.)

Mine drainage:
*Geology in the vicinity of anthracite-mine drainage projects, Pennsylvania
J. F. Robertson (Mt. Carmel, Pa.)
*Flood control, Anthracite region, Pennsylvania
M. J. Bergin (Mt. Carmel, Pa.)

Geochemical exploration methods:
Hydrogeochemical prospecting
F. C. Canney (D)
Geochemical prospecting techniques, Alaska
R. M. Chapman (D)
Geochemical halos of mineral deposits, Arizona and New Mexico
L. C. Huff (D)
Geochemical halos of mineral deposits, Utah and Nevada
R. L. Erickson (D)
Dispersion pattern of minor elements related to igneous intrusions
W. R. Griffitts (D)
Geochemical-exploration abstracts and information
E. L. Markward (D)

Analytical chemistry:
Rock and mineral chemical analysis
J. J. Fahey (W)
General rock chemical analysis
L. C. Peck (D)

Analytical chemistry—Continued
- Rapid rock chemical analysis
  - L. Shapiro (W)
- Analytical methods—water chemistry
  - M. W. Skougstad (q, D)
- Research on trace analysis methods
  - F. N. Ward (D)
- Trace analysis service and research
  - F. N. Ward (D)
- Analytical services and research
  - I. May (W)
- Analytical services and research
  - L. F. Rader, Jr. (D)
- Analytical services and research
  - R. E. Stevens (M)

Analytical chemistry—Continued
- Organic geochemistry and infrared analysis
  - I. A. Breger (W)

Spectroscopy:
- X-ray spectroscopy of ore minerals
  - I. Adler (W)
- Spectrographic analytical services and research
  - A. W. Helz (W)
- Spectrographic services and research
  - A. T. Myers (D)
- Spectrographic services and research
  - H. Bastron (M)

STATUS OF SURVEYS AND MAPPING BY THE TOPOGRAPHIC DIVISION

MAPPING ACCOMPLISHMENTS

Objectives of the National Topographic Mapping Program

The major function of the Topographic Division is the preparation and maintenance of the National Topographic Map Series covering the United States and outlying areas. This map series, comprising several series of quadrangle maps at different scales, is a fundamental part of the background research required to inventory, develop, and manage the natural resources of the country. Other Division functions are the production of related maps; periodic revision and maintenance of maps and publications; and research to improve map products, engineering techniques, and instrumental equipment.

In addition to the maps described below, the Topographic Division prepares shaded-relief maps, U.S. base maps, special maps, and also a few planimetric maps.

Procedures for obtaining copies of the maps and map products of the Survey are given on page A196.

Series and scales

All topographic surveys, except those in Alaska, are being made to standards of accuracy and content required for map publications at a scale of 1:24,000. Initial publication may be either at a scale of 1:24,000 or 1:62,500, depending on the need. If 1:62,500-scale maps are published initially, the 1:24,000-scale surveys in the form of photogrammetric compilation sheets are available on open file, and for future publication at that scale. For maps in Alaska the publication scale is 1:63,360 or "inch-to-the-mile."

Coverage of the Nation

Sixty-three percent of the total area of the 50 States, Puerto Rico, and Virgin Islands is covered by topographic surveys at scales of 1:24,000, 1:62,500, and 1:63,360 (only in Alaska). These surveys have been published as standard quadrangle maps for 55 percent of the total area. Topographic surveys for the other 8 percent are available on open file.

During fiscal 1962, 468 maps of unmapped areas equivalent to 1.3 percent of the total area were published. Another 0.6 percent heretofore covered by 15-minute maps compiled at obsolete standards was replaced by 386 new maps at 1:24,000-scale standards (fig. 6).

For the extent and location of map coverage see figure 7.

Map revision and maintenance

During 1961, 59,300 square miles of 7½-minute mapping was added to the growing backlog of maps requiring revision. During fiscal 1962, the backlog was diminished by revising 11,300 square miles of mapping, leaving 272,600 square miles of 7½-minute mapping requiring revision at the end of the year (fig. 8).

1:250,000-scale mapping

The 48 conterminous States and Hawaii are 99 percent covered by 1:250,000-scale maps originally prepared as military editions by the Army Map Service. As these maps are completed, civil editions are prepared for distribution to the public. The civil editions will be kept up to date by the Topographic Division. Maps of Alaska at this scale are being prepared and published by the Geological Survey. Coverage of the 50 States, Puerto Rico, and the Virgin Islands of the United States by 1:250,000-scale maps and the work in progress are shown on figure 9.

State maps

State maps are published at scales of 1:500,000 and 1:1,000,000 except for Alaska, which is covered by base maps published at scales of 1:1,584,000 and 1:2,500,000, and Hawaii, which is not yet covered by any of these maps.

State maps for 26 States, compiled on modern standards, have been published in a new series entailing as many as four editions: base, base and highways, base and highways and contours, and shaded relief on a modified base. As shown in figure 10, other conterminous States are covered by an earlier series.

Urban-area maps

Urban-area maps are prepared by combining on one or more sheets the 7½-minute quadrangles that cover an urban area. Maps of 53 urban areas have been published, including 1 new and 1 revised map that were completed during fiscal 1962. Work in progress includes 3 new maps and the revision of 4 others.

PUBLISHED

Albuquerque, N. Mex.
Atlanta, Ga.
Austin, Tex.
Baton Rouge, La.
Bridgeport, Conn.
Buffalo, N.Y.
Champaign–Urbana, Ill.
Chattanooga, Tenn.
Chicago, Ill. (3 sheets)
Cincinnati, Ohio
Cleveland, Ohio
Columbus, Ohio
Davenport–Rock Island–Moline, Iowa and Illinois
Dayton, Ohio
Denver, Colo.
Detroit, Mich. (2 sheets)
Duluth–Superior, Minnesota and Wisconsin
Fort Worth, Tex.
Gary, Ind.
Hartford–New Britain, Conn.
Honolulu, Hawaii
Houston, Tex.
Indianapolis, Ind.
Juneau, Alaska
Knoxville, Tenn.
Little Rock, Ark.
Los Angeles–Long Beach, Calif. (3 sheets)
Louisville, Ky.
Madison, Wis.
Milwaukee, Wis.
Minneapolis–St. Paul, Minn.
New Haven, Conn.
New Orleans, La.
New York, N.Y. (8 sheets)
Norfolk–Portsmouth–Newport News, Va.
Oakland–San Francisco, Calif. (2 sheets)
Peoria, Ill.
Pittsburgh, Pa.
Philadelphia, Pa. (2 sheets)
Portland–Vancouver, Oregon and Washington
Rochester, N.Y.
Salt Lake City, Utah
San Diego, Calif.
San Juan, P.R.
Seattle, Wash.
Shreveport, La.
Spokane, Wash.
Toledo, Ohio
Washington, D.C.
Wilkes-Barre–Pittstown, Pa.
Wilmington, Del.
Worcester, Mass.
Youngstown, Ohio

IN PROGRESS

New maps

Anchorage, Alaska
Boston, Mass.
Wichita, Kans.

Revision

Gary, Ind.
Indianapolis, Ind.
Louisville, Ky.
Washington, D.C.

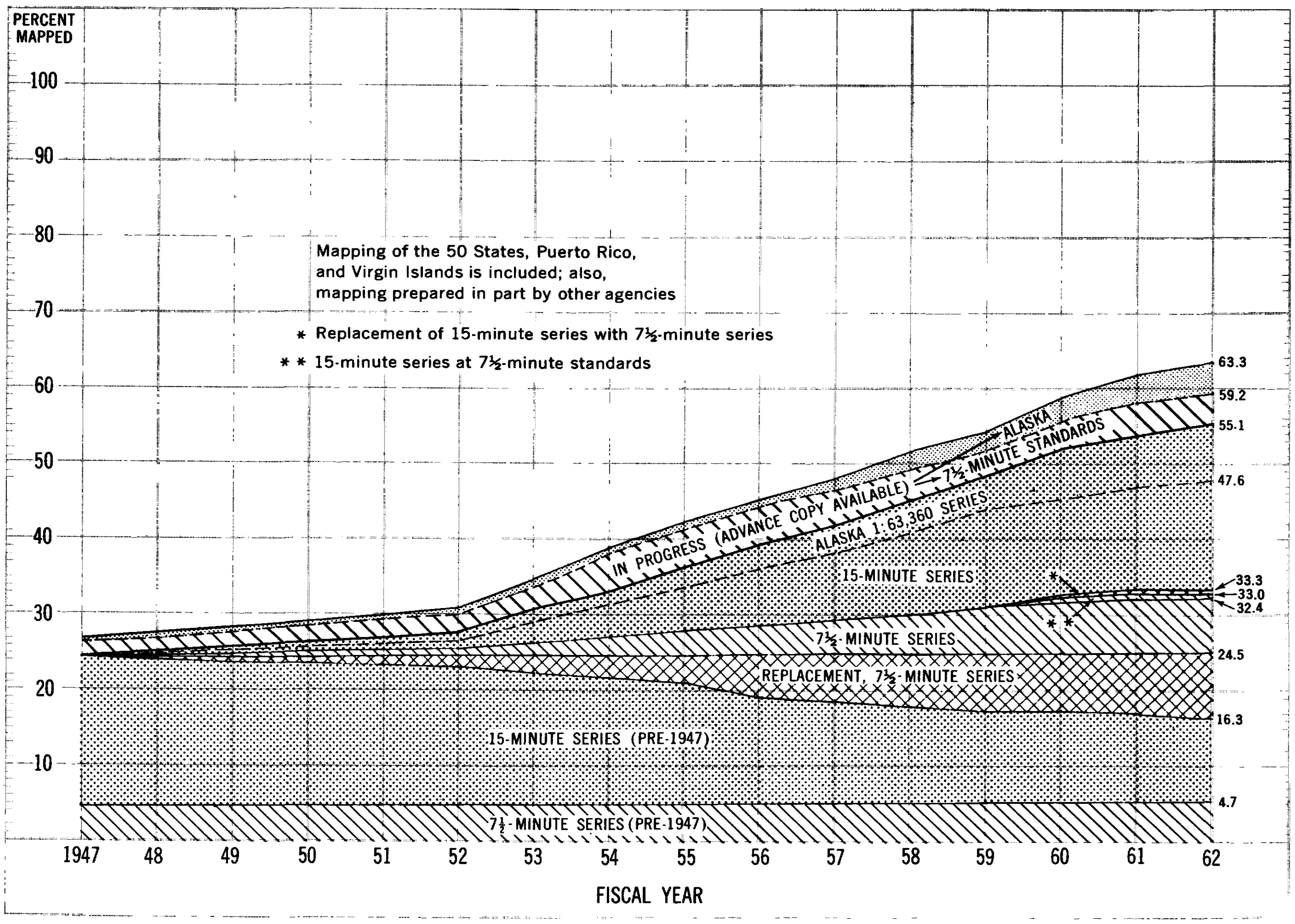

FIGURE 6.—Progress of 7½- and 15-minute quadrangle mapping.

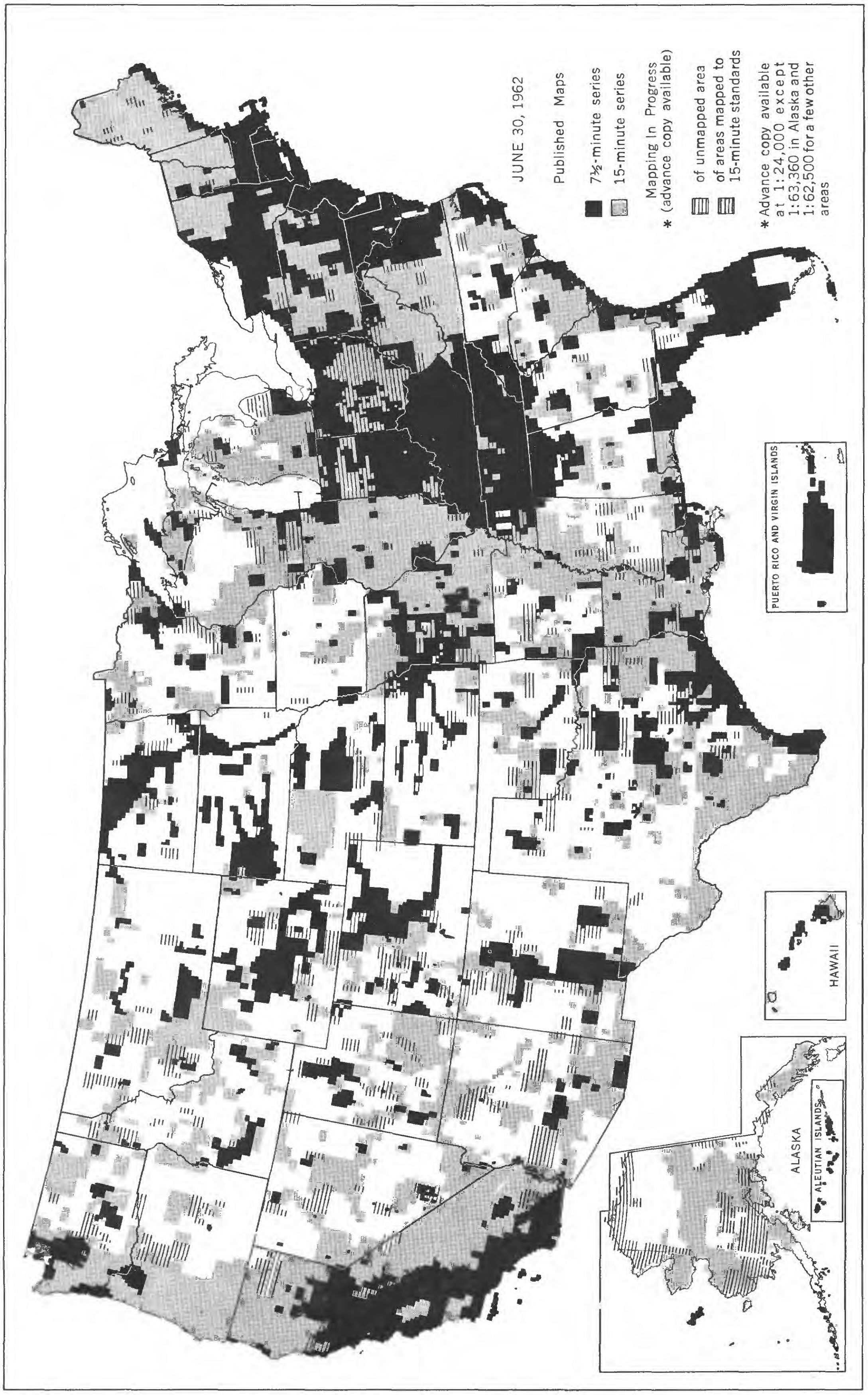

FIGURE 7.—Status of 7½- and 15-minute quadrangle mapping.

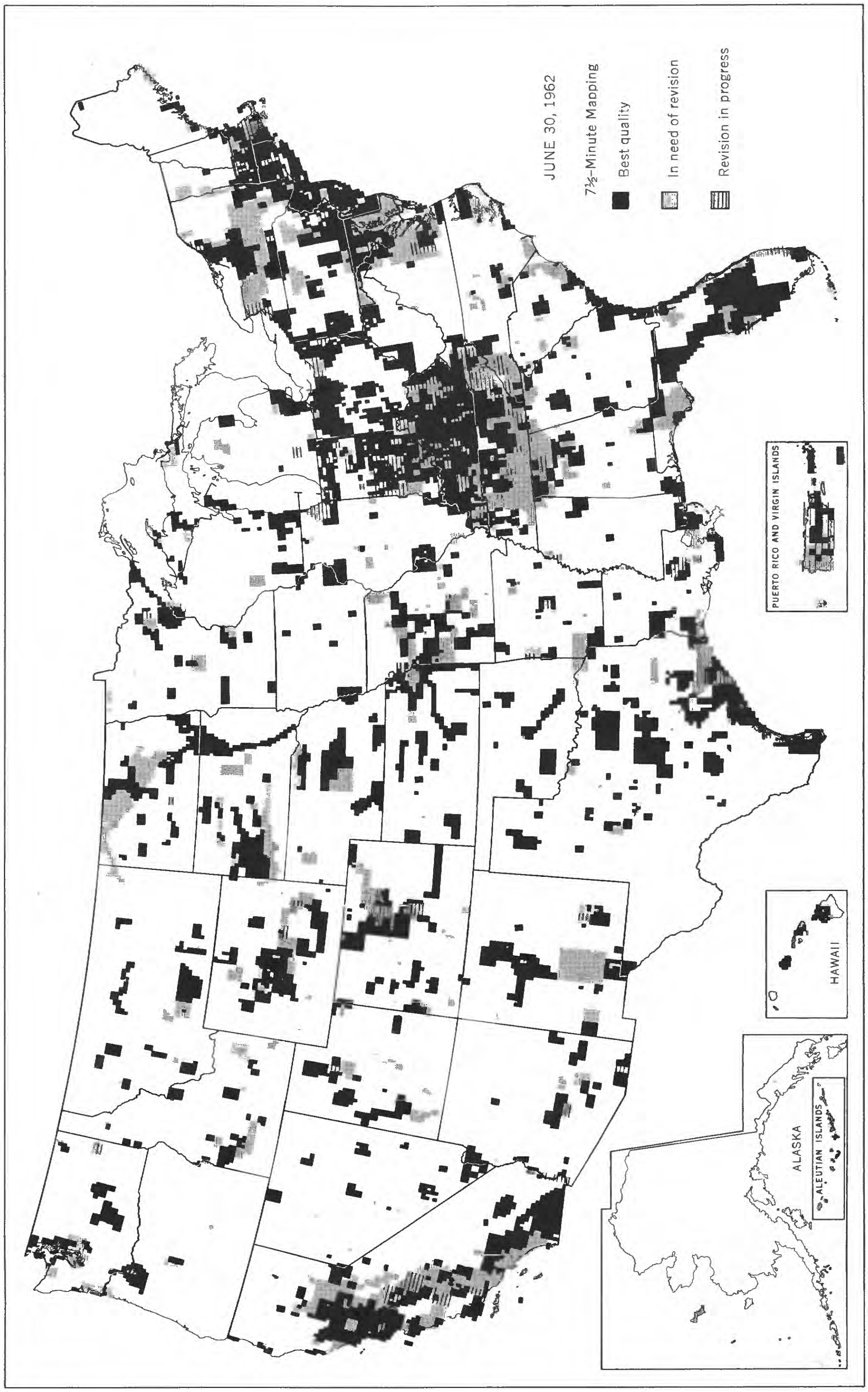

FIGURE 8.—Status of revision of large-scale mapping.

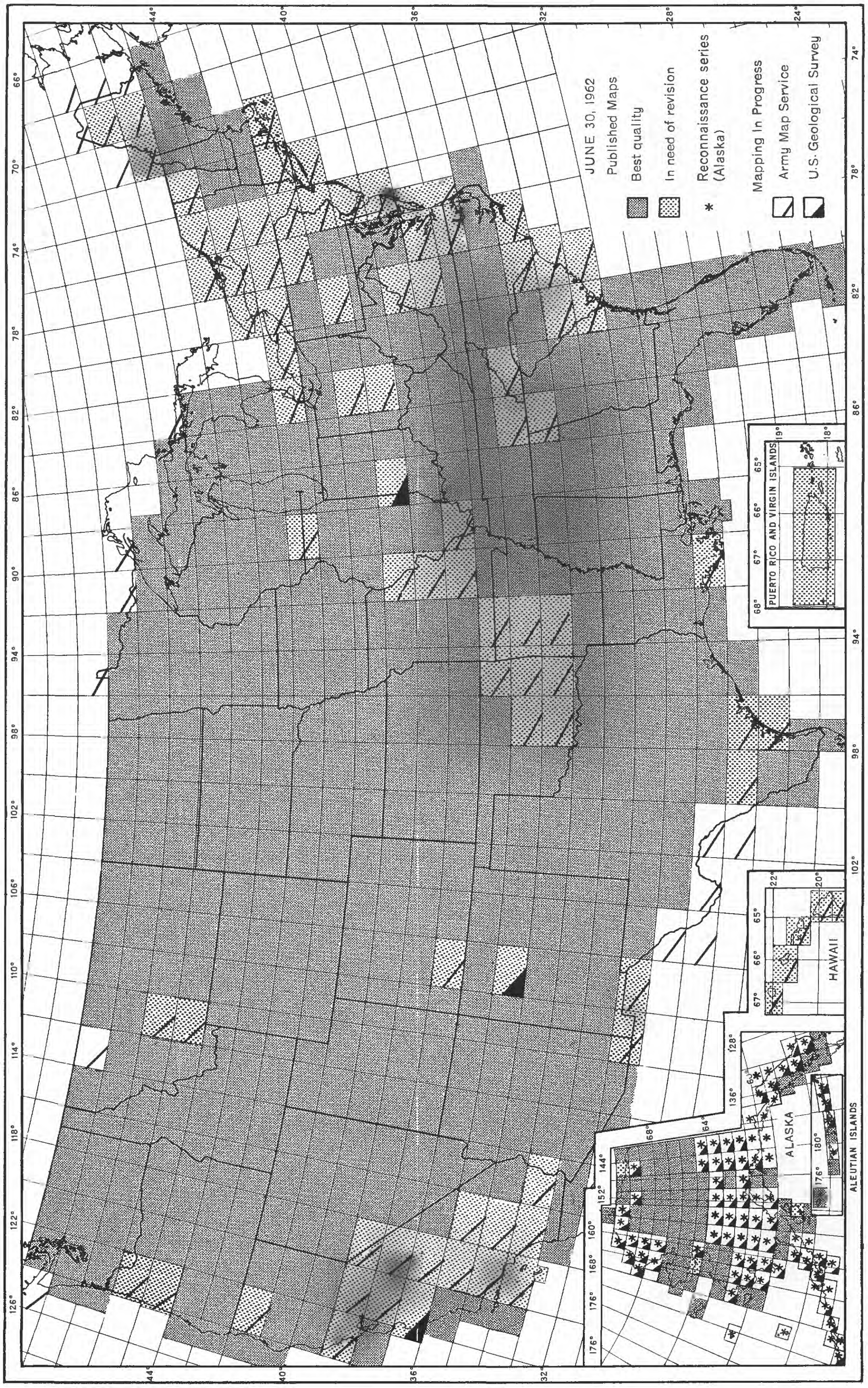

FIGURE 9.—Status of 1:250,000-scale mapping.

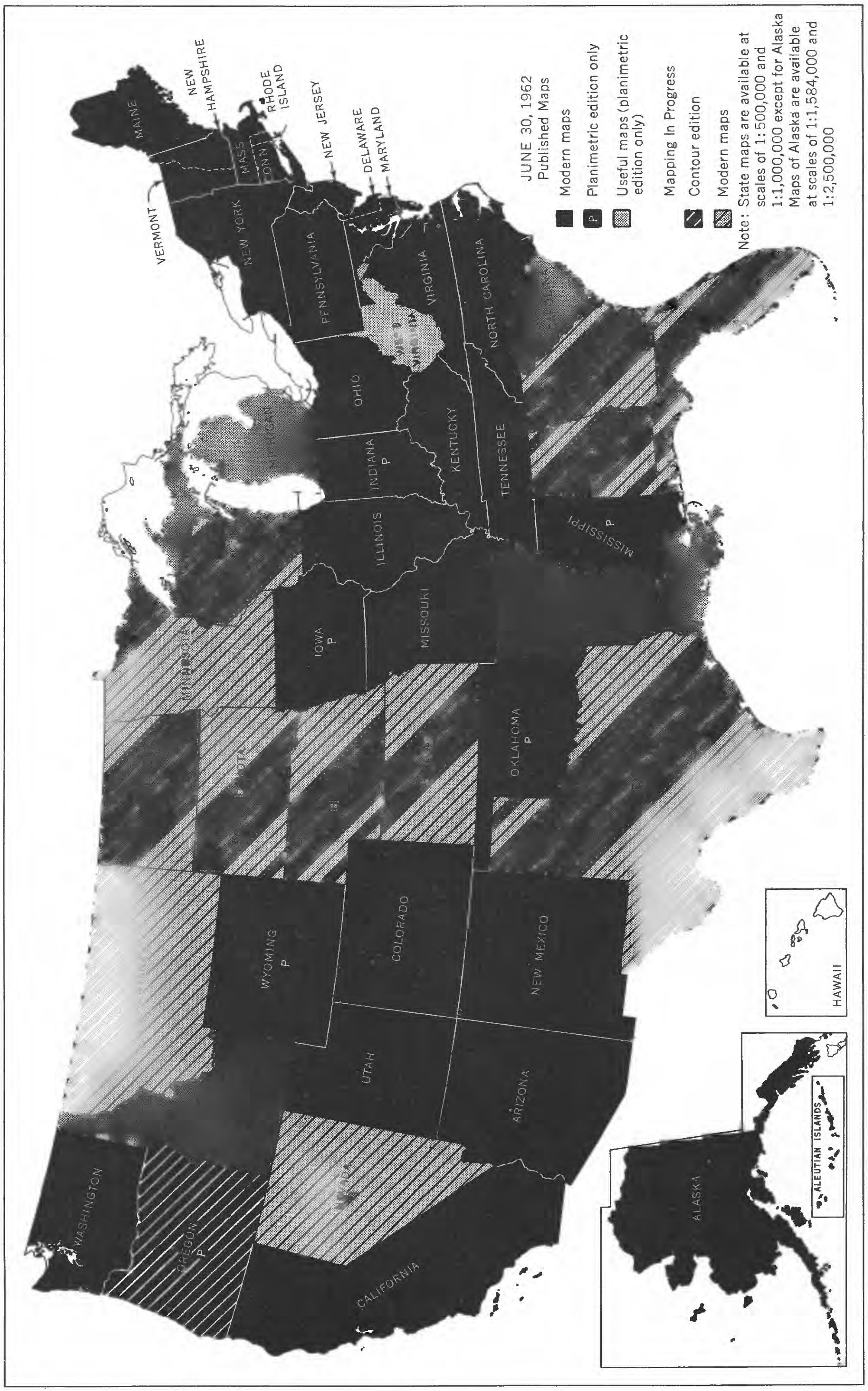

FIGURE 10.—Status of State maps.

National park maps

Maps of 43 of the 184 national parks, monuments, historic sites, and other areas administrated by the National Park Service have been published. These usually are made by combining all existing quadrangle maps into one map sheet, but occasionally surveys are made covering only the park area. Published maps in this series include:

Acadia National Park, Maine
Bandelier National Monument, N. Mex.
Black Canyon of the Gunnison National Monument, Colo.
Bryce Canyon National Park, Utah
Canyon de Chelly National Monument, Ariz.
Carlsbad Caverns National Park, N. Mex.
Cedar Breaks National Monument, Utah
Chicamauga and Chattanooga National Military Park, Ga.
Colonial National Historical Park (Yorktown), Pa.
Colorado National Monument, Colo.
Crater Lake National Park and Vicinity, Oreg.
Craters of the Moon National Monument, Idaho
Custer Battlefield, Mont.
Devils Tower National Monument, Wyo.
Dinosaur National Monument, Utah-Colorado
Franklin D. Roosevelt National Historic Site, N.Y.
Glacier National Park, Mont.
Grand Canyon National Monument, Ariz.
Grand Canyon National Park, Ariz. (2 sheets)
Grand Teton National Park, Wyo.
Great Sand Dunes National Monument, Colo.
Great Smoky Mountains National Park, North Carolina and Tennessee (2 sheets)
Hot Springs and Vicinity, Ark.
Isle Royale National Park, Mich.
Lassen Volcanic National Park, Calif.
Mammoth Cove National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
Olympic National Park and Vicinity, Wash.
Petrified Forest National Monument, Ariz.
Rocky Mountain National Park, Colo.
Scotts Bluff National Monument, Nebr.
Sequoia and King's Canyon National Parks, Calif.
Shenandoah National Park, Va. (2 sheets)
Shiloh National Military Park, Tenn.
Vanderbilt Mansion National Historic Site, N.Y.
Vicksburg National Military Park, Miss.
Wind Cave National Park, S. Dak.
Yellowstone National Park, Wyoming, Montana and Idaho
Yosemite National Park, Calif.
Zion National Park (Kolob Section), Utah
Zion National Park (Zion Canyon Section), Utah

Million-scale maps

The worldwide million-scale series of topographic quadrangle maps was originally sponsored by the International Geographical Union and designated the International Map of the World on the Millionth Scale (IMW). The conterminous United States will be covered by 53 maps, 17 of which were produced before 1955. At that time the Army Map Service began military series at 1:1,000,000 scale. Eventually these AMS maps will be modified slightly and published in the IMW series (fig. 11).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW but are covered by AMS maps. Both the IMW and AMS series are available for Mt. Shasta, Point Conception, Mississippi Delta (White Lake-AMS), Hatteras, Chesapeake Bay, and Boston. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterrey maps, and Canada, the Regina and Montreal maps. Puerto Rico is covered by two maps, each compiled and published by the American Geographical Society and the Army Map Service.

NATIONAL ATLAS

In 1961 the Secretary of the Interior approved a recommendation of the National Academy of Sciences to have the Geological Survey undertake the production of a national atlas. During 1962, arrangements have been completed with the Library of Congress for the loan of Arch C. Gerlach, Chief of the Map Division and Incumbent of the Chair of Geography at the Library of Congress, to serve for at least 2 years as the chief of the Geological Survey's atlas project. Work on the new atlas will continue under close coordination with other agencies, professional organizations, and authorities on atlases.

Studies are in progress to determine the most appropriate organization, specifications, content, optimum sources of information, and most effective methods of presenting this information. Actual production operations will be started in fiscal year 1963.

GEOGRAPHIC NAMES

As part of normal mapping operations, fieldmen and editors investigate the names of places and natural features appearing on topographic maps. The name in general use by local residents is accepted when such usage is unanimous and not in conflict with names appearing on previously published maps and publications. When a name conflict is discovered, the evidence gathered during the field investigation, with the name recommended by the Geological Survey, is referred to the Board on Geographic Names for a decision.

The Board on Geographic Names, with the Secretary of the Interior, is responsible for maintaining uniform geographic nomenclature on Federal maps and publications. Problems concerning names in the United States and its possessions are handled by the Domestic Names Committee of this board. The Committee consists of one representative each from the Departments of Agri-

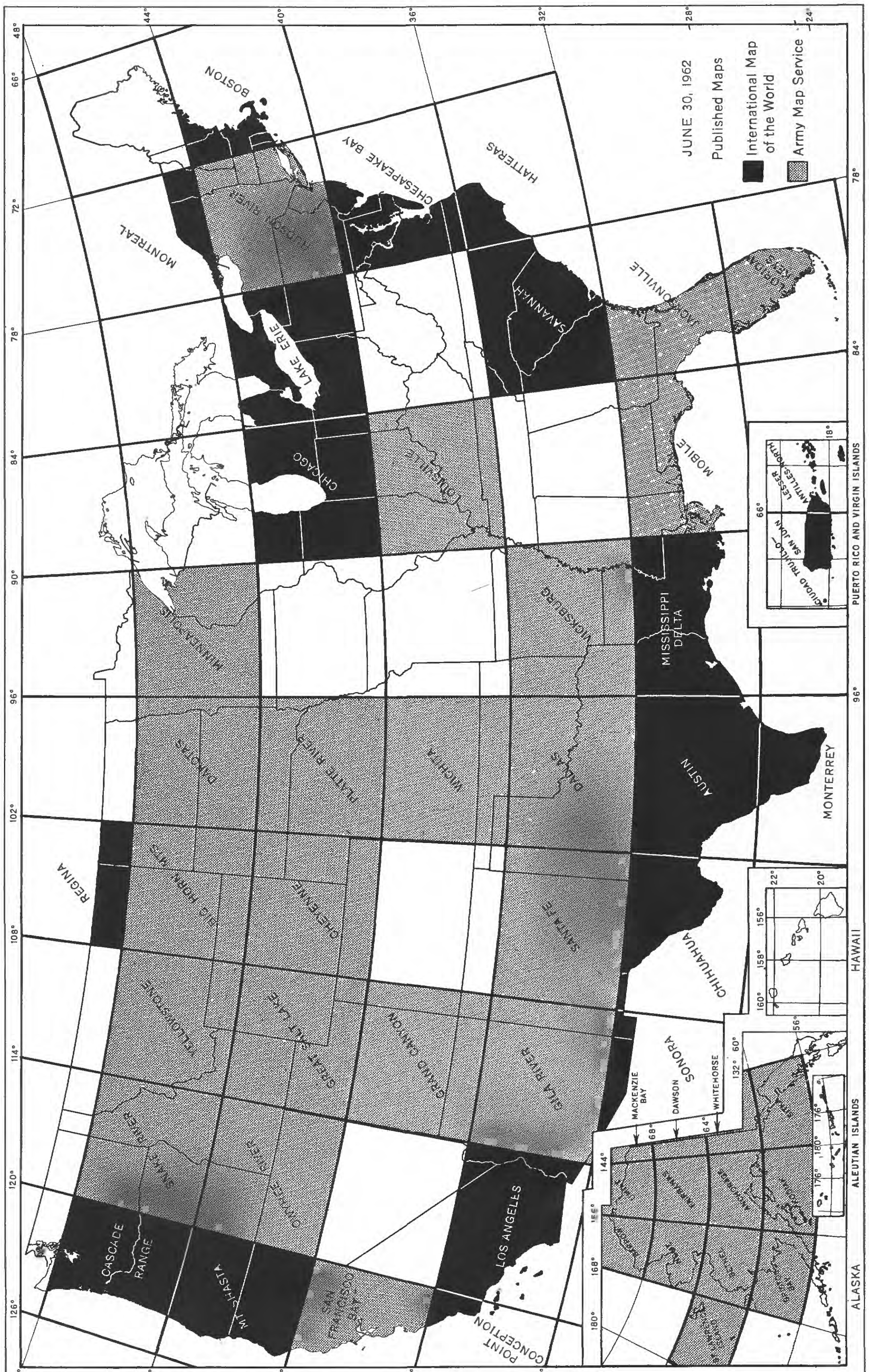

FIGURE 11.—Status of 1:1,000,000-scale topographic maps.

culture, Commerce, and Interior, and the Post Office Department and the Government Printing Office. Names approved by the Board on Geographic Names are published in decision lists issued three or more times each year and distributed to government agencies and the public free upon request.

Staff assistance to the Domestic Names Committee has been provided by the Geological Survey since 1958. The assistance includes background research on name questions and the preparation of decision lists for publication. Ten decision lists, containing a total of 4,929 approved names, have been published since 1958.

HOW TO OBTAIN GEOLOGICAL SURVEY PUBLICATIONS

All book publications, maps, and charts published by the Survey are listed in "Publications of the Geological Survey," and in supplements, which keep the list up to date. New releases are announced each month in "New Publications of the Geological Survey." All of these lists of publications are free upon request to the GEOLOGICAL SURVEY, WASHINGTON 25, D.C. They may be consulted at many public and educational-institution libraries, and at the Geological Survey offices named below.

Books, maps, charts, and folios that are out of print can no longer be purchased from any official source. They may be consulted at many libraries, and some can be purchased from dealers in second-hand books.

ORDERING BOOK REPORTS

Professional papers, bulletins, water-supply papers and miscellaneous book publications can be purchased from the SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON 25, D.C. Prepayment is required and may be made by money order or check payable to that office, or in cash—exact amount—at sender's risk. Postage stamps are not accepted. Book publications also may be purchased on an over-the-counter basis from the following Geological Survey offices: 468 NEW CUSTOMHOUSE, DENVER, COLO.; 437 FEDERAL BUILDING, SALT LAKE CITY, UTAH; 602 THOMAS BUILDING, DALLAS, TEX.; 1031 BARTLETT BUILDING, LOS ANGELES, CALIF.; 232 APPRAISERS BUILDING, SAN FRANCISCO, CALIF.; SOUTH 157 HOWARD ST., SPOKANE, WASH.; and 503 CORDOVA BUILDING, ANCHORAGE, ALASKA.

Circulars may be obtained free on application to the GEOLOGICAL SURVEY, WASHINGTON 25, D.C.

ORDERING MAPS AND CHARTS

Maps, charts, folios, and hydrologic atlases are sold by the Geological Survey. Mail orders for those covering areas east of the Mississippi River should be addressed to the GEOLOGICAL SURVEY, WASHINGTON 25, D.C., and for areas west of the Mississippi River to the GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER 25, COLO. Remittances should be sent by check or money order made payable to the Geological Survey or in cash—exact amount—at the sender's risk. Postage stamps are not accepted. Retail prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual states. On an order amounting to $10 or more at the retail price, 20 percent discount is allowed; on orders of $60 or more, 40 percent discount is allowed. These publications also may be obtained, on an area basis, by over-the-counter sale (but not by mail) from the other Geological Survey offices mentioned above. Residents of Alaska may order Alaska maps from the GEOLOGICAL SURVEY, 520 ILLINOIS ST., FAIRBANKS, ALASKA. Most geologic maps are available flat, or folded in envelopes.

The various types of maps and map products prepared by the Topographic Division are discussed in the section beginning on page A187.

Indexes to topographic-map coverage of the various States are released periodically and are free on application. The release of revised indexes is announced in the monthly list of new publications of the Geological Survey. Each State index shows the areas mapped and gives lists of Geological Survey offices from which maps may be purchased and of local agents who sell the maps.

Advance material available from current topographic mapping is indicated on quarterly releases of State index maps. This material, including such items as aerial photography, geodetic-control data, and preliminary maps in various stages of preparation and editing, is available for purchase. Information concerning the ordering of these items is given on each State index. Requests for indexes or inquiries concerning availability of advance materials should be directed to the MAP INFORMATION OFFICE, U.S. GEOLOGICAL SURVEY, WASHINGTON 25, D.C.

OPEN-FILE REPORTS

Open-file reports are a nonpermanent form of publication. They include unpublished manuscript reports, maps, and other material made available for public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date and places of availability for consultation by the public are given in press releases or other forms of public announcement. In general, open-file reports are placed in one or more of the three Geological Survey libraries: ROOM 1033, GENERAL SERVICES BLDG., WASHINGTON, D.C.; BLDG. 25, FEDERAL CENTER, DENVER, COLO.; and 345 MIDDLEFIELD ROAD, MENLO PARK, CALIF. Other depositories may include one or more of the Geological Survey offices listed on page A128 to A132, or interested State agencies. Many open-file reports are replaced later by formally printed publications.

PUBLICATIONS IN FISCAL YEAR 1962

Listed below are citations of technical reports of the Conservation, Geologic, Topographic, and Water Resources Divisions published or otherwise released to the public during the fiscal year 1962. The list also includes some publications that were not listed in either Professional Papers 400-A or 424-A. It does not include a few articles that are dated prior to July 1, 1962, but were released after that date.

Abrahams, J. H., Jr., Baltz, E. H., Jr., and Purtymun, W. D., 1962, Movement of perched ground water in alluvium near Los Alamos, New Mexico: Art. 37 in U. S. Geol. Survey Prof. Paper 450-B, p. B93-B94.

Abrahams, J. H., Jr., Weir, J. E., Jr., and Purtymun, W. D., 1961, Distribution of moisture in soil and near-surface tuff on the Pajarito Plateau, Los Alamos County, New Mexico: Art. 339 in U. S. Geol. Survey Prof. Paper 424-D, p. D142-D145.

Adams, J. K., and Boggess, D. H., 1962, Water-table, surface-drainage, and engineering soils map of the St. Georges area, Delaware: U. S. Geol. Survey open-file report.

Adams, J. W., and Young, E. J., 1961, Accessory bastnaesite in the Pikes Peak granite, Colorado: Art. 254 in U. S. Geol. Survey Prof. Paper 424-C, p. C292-C294.

Akin, P. D., Murray, C. R., and Theis, C. V., 1962, Five ground-water investigations for U. S. Army Airfield near Fort Sumner, New Mexico: New Mexico State Engineer, 16th-17th Bienn. Repts., July 1, 1942-June 30, 1946, p. 293-322.

Adler, Isidore, and Dwornik, E. J., 1961, Electron probe analysis of schreibersite (rhabdite) in the Canyon Diablo meteorite: Art. 112 in U. S. Geol. Survey Prof. Paper 424-B, p. B263-B265.

Adler, Isidore, and Massoni, C. J., 1962, Simple X-Y translation stage and indexing mechanism: Rev. Sci. Instruments, v. 33, no. 2, p. 247.

Adolphson, D. G., 1961a, Geology and ground-water resources of the Drake area, McHenry County, North Dakota: North Dakota State Water Conserv. Comm., North Dakota Ground-Water Study 14, 44 p.

——— 1961b, Glacial drift aquifers in the Gackle area, Logan and Stutsman Counties, North Dakota: North Dakota State Water Conserv. Comm., North Dakota Ground-Water Study 33, 16 p.

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LIST OF CORRECTIONS TO PROFESSIONAL PAPERS 400-A, 400-B, 424-A, 424-B, 424-C, 424-D, AND 450-B

Following is a list of corrections of the significant errors that have appeared in "Geological Survey Research 1960" (Professional Papers 400-A and -B), "Geological Survey Research 1961" (Professional Papers 424-A, -B, -C, and -D), and in Chapter B of this volume. Readers are urged to note these corrections in their copies of previous chapters.

Corrections to the text are located by volume, page, article, left or right column, and line as counted from the top of the column in that article (all equations counted as one line only). Corrections to figures are located by volume, page, article, and figure number.

Professional Paper 400-A

a. Page A63, line 2 of footnote 2: change "186" to "1.86."

Professional Paper 400-B

a. Page B38, article 19, figure 19.1: in title, change "acres" to "areas."
b. Page B48, article 24: in authorship, change "Hoyle" to "Hoye."
c. Page B51, article 24, right column, line 2: change "12" to "8."
d. Page B55, article 26, left column, line 9: change "6,450-level" to "6,400-level."
e. Page B202, article 89, right column, line 13: change "fig. 89.2" to "fig. 89.3."
f. Page B203, article 89, left column, line 1: change "fig. 89.1a" to "fig. 89.1."
g. Page B203, article 89, left column, line 8: change "figure 89.1b" to "figure 89.2."
h. Page B203, article 89, left column, line 34: change "fig. 89.3" to "fig. 89.4."
i. Page B232, article 104, right column, line 41 (7th line from bottom): change "Pennsylvanian" to "Mississippian."
j. Page B499, article 227, figure 227.2: correct title should read as follows "Spectra, cyanogen region, of silicate rock standards containing tungsten, thallium, and ruthenium: *a*, in controlled atmosphere of 4 parts of argon and 1 part of oxygen, *b*, in air."
k. Page B503, article 229, figure 229.1: all numbers in upper abscissa ("Millivolt reading with sodium-sensitive electrode") should be preceded by minus sign.

Professional Paper 424-A

a. Page A78, left column, line 10: line should read "with Al_2O_3 increasing toward and K_2O increasing away."

Professional Paper 424-B

a. Pages B18 and B19, article 8, figures 8.2 and 8.3: titles of these 2 figures should be reversed.
b. Page B48, article 23, left column, line 17: change "lb ft^{-2}" to "lb in^{-2}."
c. Page B63, article 29, right column, lines 19 and 20: correct to read as follows "in which R_{th} is the resistance of the thermistor. This means that when measuring resistance the dial reads directly from 0 to 10,000 ohms - - - -."
d. Page B168, article 70, figure 70.1: in stratigraphic column 1 change sample number from "G3043" to "G3123."

Professional Paper 424-C

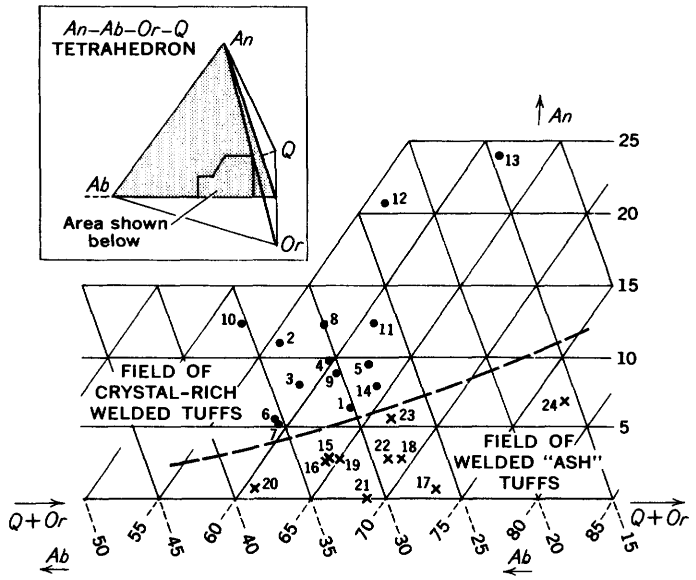
a. Page C43, article 164: in title of article change "Special" to "Specific."
b. Page C88, article 183, figure 183.1: table 183.1, referred to in figure, was omitted from article. This article will be reprinted in full in Professional Paper 450-E.
c. Page C150, article 203, right column, line 17: change "joined" to "jointed."
d. Page C197, article 219, table 219.2, second column from right: change "microhms" to "micromhos."
e. Page C222, article 229, figure 229.1: in explanation of section, change "chert" to "flow breccia."
f. Page C252, article 239, table 239.1: add the following to the upper part of table:

Vegetation	Stony soil		Shale-derived soil	
	Percent composition	Hits per 100 pins	Percent composition	Hits per 100 pins
Grasses				
Agropyron smithii (Rydb.) Western wheatgrass	------	------	13. 2	13. 1
Andropogon gerardi (Vitman.) Big bluestem	7. 4	6. 7	------	------
Andropogon scoparius (Michx.) Little bluestem	6. 8	6. 1	------	------
Bouteloua curtipendula (Michx.) Torr. Sideoats grama	8. 4	7. 6	------	------
Bouteloua gracilis (H.B.K.) Lag. Blue grama	14. 1	12. 8	6. 0	6. 0
Bouteloua hirsuta (Lag.) Hairy grama	7. 0	6. 4	------	------
Buchloe dactyloides (Nutt.) Engelm. Buffalograss	------	------	25. 4	25. 2
Bromus japonicus (Thunb.) Japanese brome	------	------	41. 8	41. 4
Koeleria cristata (L.) Pers. Junegrass	2. 2	2. 0	------	------

Professional Paper 424-D

a. Page D46, article 310, right column, lines 16 and 17: should read "here indicates that the east side of the zone moved south relative to the west side."

b. Page D78, article 320, figure 320.3: a corrected version of parts of this figure is reproduced below.



c. Page D90, article 324, right column, line 22: change "important" to "only."

d. Page D216, article 365, figure 365.1: title should read "Aerial view of mangrove swamp south of Gladstone, Queensland, Australia. White area is vegetation free."

e. Page D220, article 367, figure 367.1: title should read "Index map of Java showing the distribution of phosphate deposits (after van Es, 1935)."

f. Page D220, article 367: add the following Reference Cited: Es, L. J. C. van, 1935, de beteekenis en het voorkomen van phosphaat op Java: De Ingenieur in Nederlandsch-Indie, IV. Mijnbouw en Geologie, "De Mijningenieur," V.2, p. 34–47.

g. Page D400, article 434, right column, line 43 (6th from bottom): change "points from equation 1" to "points from equation 2."

Professional Paper 450–B

a. Page B41, article 15, left column, line 17: equation should be as follows:

$$n=100\frac{(\gamma s-\gamma d)}{\gamma s}$$

b. Page B87, article 34, left column: equation on line 12 should be numbered (1), equation on line 25 should be numbered (2), and equation on line 35 should be numbered (3).

c. Page B114, article 48, right column, line 17 (last line): change "620μ" to "620mμ."

d. Page B128, article 53, left column, line 5: equation should read as follows:

$$Al^{+3}+3OH^{-1}\rightleftharpoons\left\{\begin{array}{c}Al(OH)_3\\ H_3AlO_3\end{array}\right\}\underset{\text{solid}}{\rightleftharpoons} AlO_2^{-1}+H^{+1}+H_2O$$

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[See also "Regional Investigations," p. A137–A168, and "Topical Investigations," p. A169–A186]

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